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# Ship hull plating weld misalignment effects when subjected to tension

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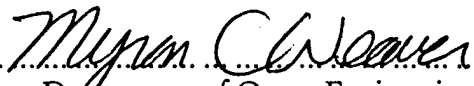# Ship Hull Plating Weld Misalignment Effects when Subjected to Tension
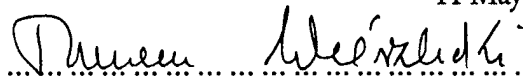
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California Polytechnic State University San Luis Obispo, 1986
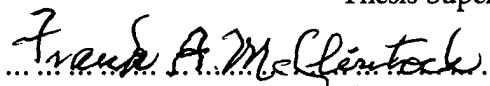
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# Ship Hull Plating Weld Misalignment Effects when Subjected to Tension

by

M. Cameron Weaver

## Abstract

Precision fabrication of ships is advancing. Welding is ubiquitous in ship construction and military standards have specified tolerances for joining plates in naval combatants. Precision manufacturing will allow the production of ships with smaller hull plate misalignments. A benefit from this could be improved ship survivability when subjected to underwater explosions. Slip Line Fracture Mechanics interacting with Finite Element Analysis (FEA) gives insight into the deformation, necking and fracture mechanisms of typical over-matched welds. The weld rotates with local necking until the plates are aligned and then shears off.

FEA showed the importance of deformed geometry in promoting final fracture by slip from the toe of the weld in non-hardening material. Graphical results indicate that for a non-hardening material with an offset of 15% of the plate thickness, which is within current military standards, weld rotation of 4-6° and local plate thinning of 4-5% in the region next to the weld can be expected. A test specimen showed a 4° weld rotation but did not provide the plane-strain condition and failed by necking away from the weld. A re-design is suggested.

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# Chapter 1 Introduction

## 1.1 Need

The Office of Naval Research (ONR) has a keen interest in the possible applications of precision manufacturing of ship hull structures. The United States Navy is exploring the use of precision manufacturing for future shipbuilding. This research addresses the possible benefits of precision welding with reduced misalignments when ship hull plates are subjected to an underwater explosion (UNDEX). Misalignment could either be angular or plate offset. Offset of the plates will be the kind studied in this paper.

Offsets in welds can easily arise in welding sections with beams of 10 m and 10 mm hull plating (see Figure 1). Figure 2 shows the visible welded joints of a finished combatant.
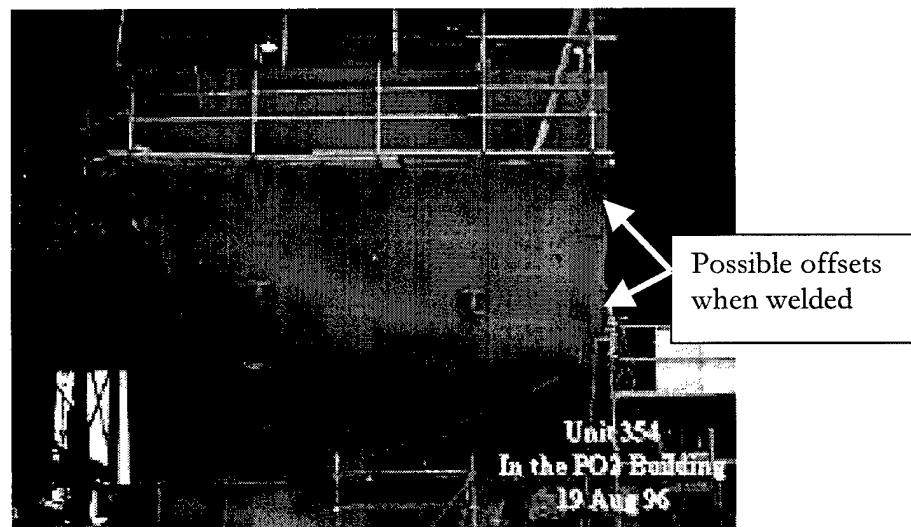


Figure 1. Transom module construction [1].
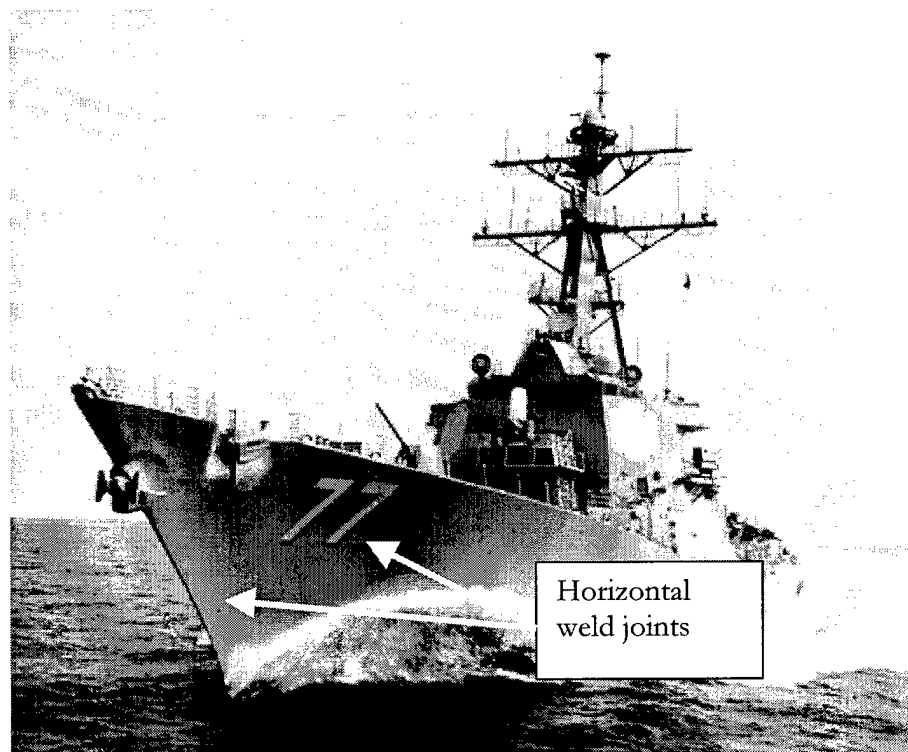
Figure 2. Finished horizontal welded joints [1].

Figure 3 shows the geometry of ship hull plating with an offset for a typical welded joint of the kind that will be explored in this research.
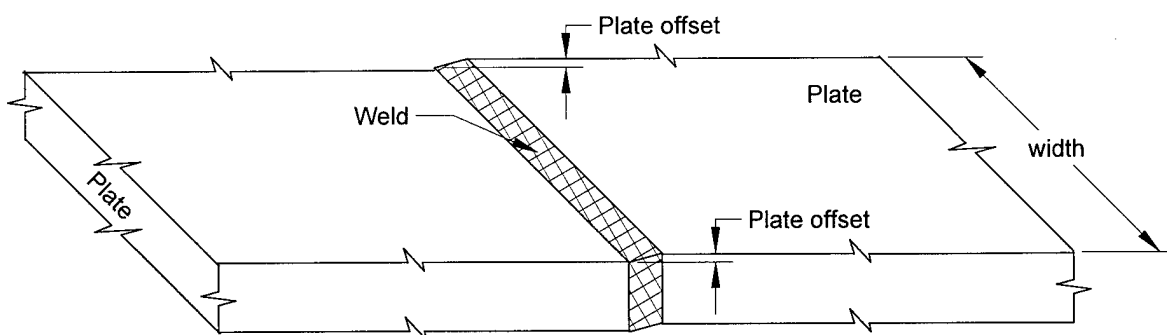


Figure 3. Plate offset.

## 1.2 Prior Work

Extensive research has addressed the strength of weldments in ship hull plating, but none were found on the effect on the offset on the tensile behavior. For example Ship Structural Committee Report, SSC-4, by Snelling (1946) [2], addressed the effects on welded plates when subjected to explosions; however, the specific problem of plate misalignment was not characterized or explored. As reference for future research into this effect of UNDEX, Ship Structural Committee Report, SSC-6, Davis (1948) [3], et al., investigated the fracture of welded flat plates by subjecting them to a bend test simulating explosions. Ship Structural Committee Report, SSC-335, by Dexter (1986) [4], et al., had good hardness profiles from underwater welding. This result was compared with data obtained from welding EH-36 in air. Nguyen (1998) [5], et al., studied the effect of weld geometry and fatigue characteristics due to the welds. Plate angular misalignment and offset affects under compression were studied by Cui (1999) [6], et al.. In conclusion, the plethora of papers published about welded plates has failed to quantify the effect of plate misalignment when the plate is subjected to tension

The perfect alignment of plating on such a large scale as a ship's hull is difficult. Military standards concerning plate offset have been developed. Table 1 shows the accepted tolerances for butt welds.

Table 1. Allowable butt weld offsets [7].

| Plate Thickness (in) | Allowable Offset (in) | Allowable Offset % |
|---|---|---|
| Less than 3/8 | 1/16 | ≥16.67 % |
| 3/8 to 3/4 | 1/8 | 16.67 – 25 % |
| over 3/4 to 1-1/2 | 3/16 | 12.5 – 25 % |
| over 1-1/2 | 1/4 | ≤16.67 % |

Typical ship building practices produce no more than 1/16 of an inch offset regardless of the thickness of the plate welded [8]. However, localized offsets can be at the maximum allowed in Table 1. An offset of 15% of the plate thickness was used throughout this paper as a reasonable compromise.

# Chapter 2 Slip Line Analysis

## 2.1 Statement of Problem

To reduce cost of the new class of Amphibious Assault ship (LPD-17), the U. S. Navy has opted to use commercial grade steel, a "mild" steel, EH-36. The characteristics of EH-36 steel have been studied extensively. For strength in welded joints, the hardness of a weld is greater than the base metal (over-matching). The volume between the weld and the base metal is called the heat-affected zone (HAZ) as shown if Figure 4, where h is the plate thickness and m is the fraction of the plate thickness corresponding to the offset. Being next to the base metal it is cooled rapidly and is harder (see Figure 5).
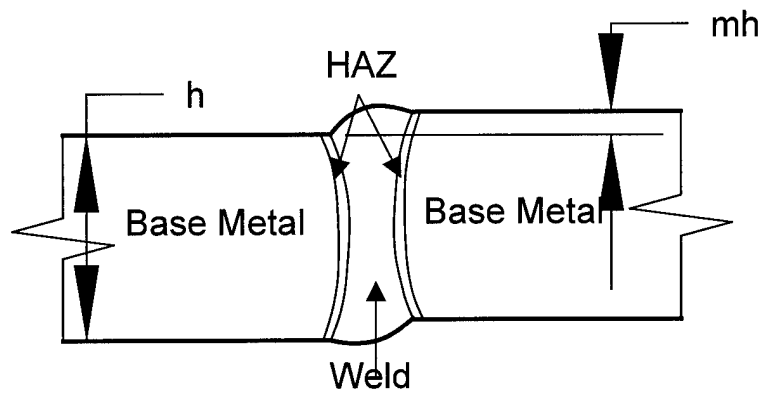
Figure 4. Geometry of a welded joint (weldment).
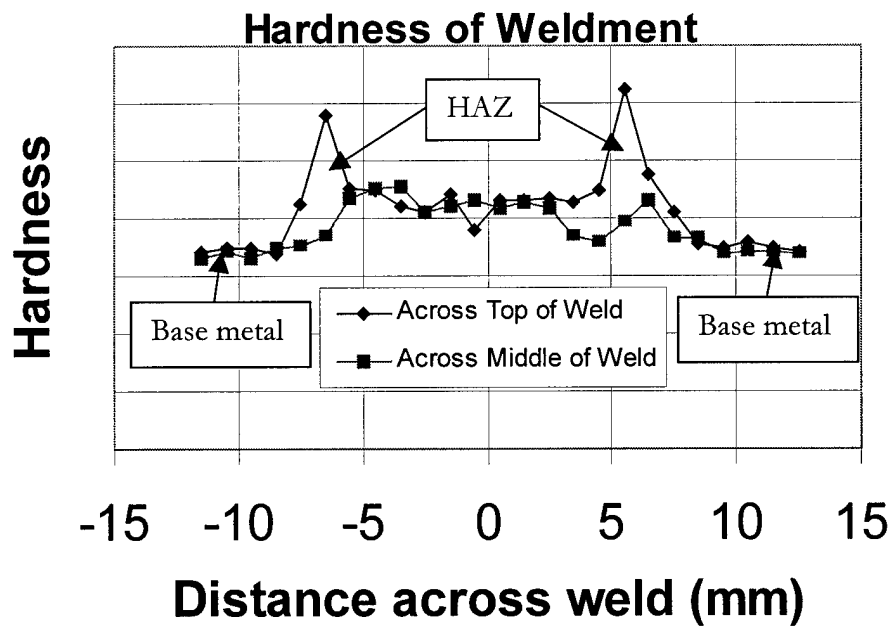


Figure 5. EH-36 weld hardness profile [9].

## Chapter 3 Slip Line Field Theory

### 3.1 Assumptions

The loading of the ship plating when subjected to an UNDEX is a dynamic event. However, for local analysis, quasi-static equilibrium conditions will be assumed. This is justified by the nature of the critical damage caused by an UNDEX, extending over many plate thicknesses, perhaps up to a few frame spacings. The time for such damage to develop is large compared to that for spall fracture or shearing at supports. This time is sufficient for the stress wave to travel through the plate thickness many times, establishing local quasi-static equilibrium.

A rigid-perfectly plastic material will be assumed (see Figure 6) during the application of slip line field theory. This is considered accurate because elastic strain at yield for typical structural steel is on the order of 0.2% [10]. Therefore, for the deformation taken well into plasticity, elastic strains can be neglected. The strain before fracture due to an UNDEX are large compared to its elastic strain.



$\sigma_y$ = yield stress
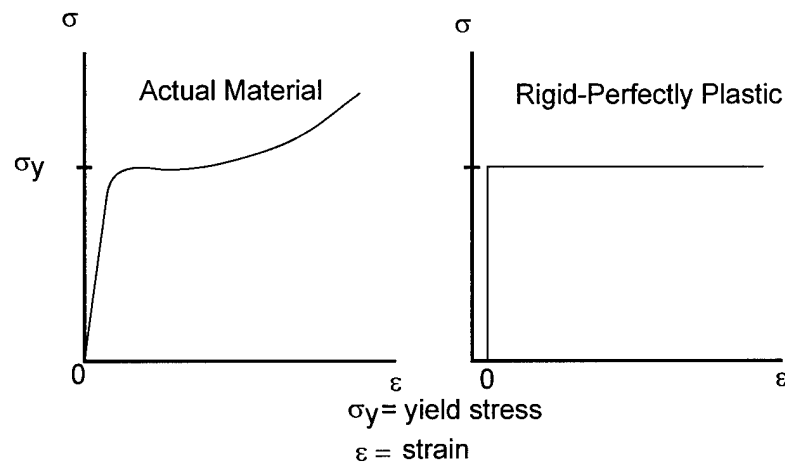
$\varepsilon$ = strain

Figure 6. Stress-strain curves of an actual vs. rigid-perfectly plastic material.

Since the normal ship building practice is to have the weld over-matched, it is reasonable to assume the weld and heat-affected zone as being a rigid body. The width of the HAZ is small when compared to the plate thicknesses under consideration [11], so its width will be assumed to be negligible and lumped into the weld. In this rigid-perfectly plastic model, in plasticity, the material is homogenous and stress throughout it is constant and equal to the yield stress, $\sigma_y$ or 2k. The following summarizes the assumptions to be used:

    a. Plane strain

b. Non-hardening material

c. Rigid-perfectly plastic material behavior

d. Uniform stress under a free surface - as a consequence in a deforming region.

The following treatment is taken from McClintock (2000) [12]. In a region on the top surface, presumably deforming in tension, two elements are drawn adjacent to the top surface at points A and B in Figure 7. There is no traction acting on the free surface. Therefore, the normal stress, $\sigma_{yy}$, and the shear stress, $\sigma_{xy}$, are zero.
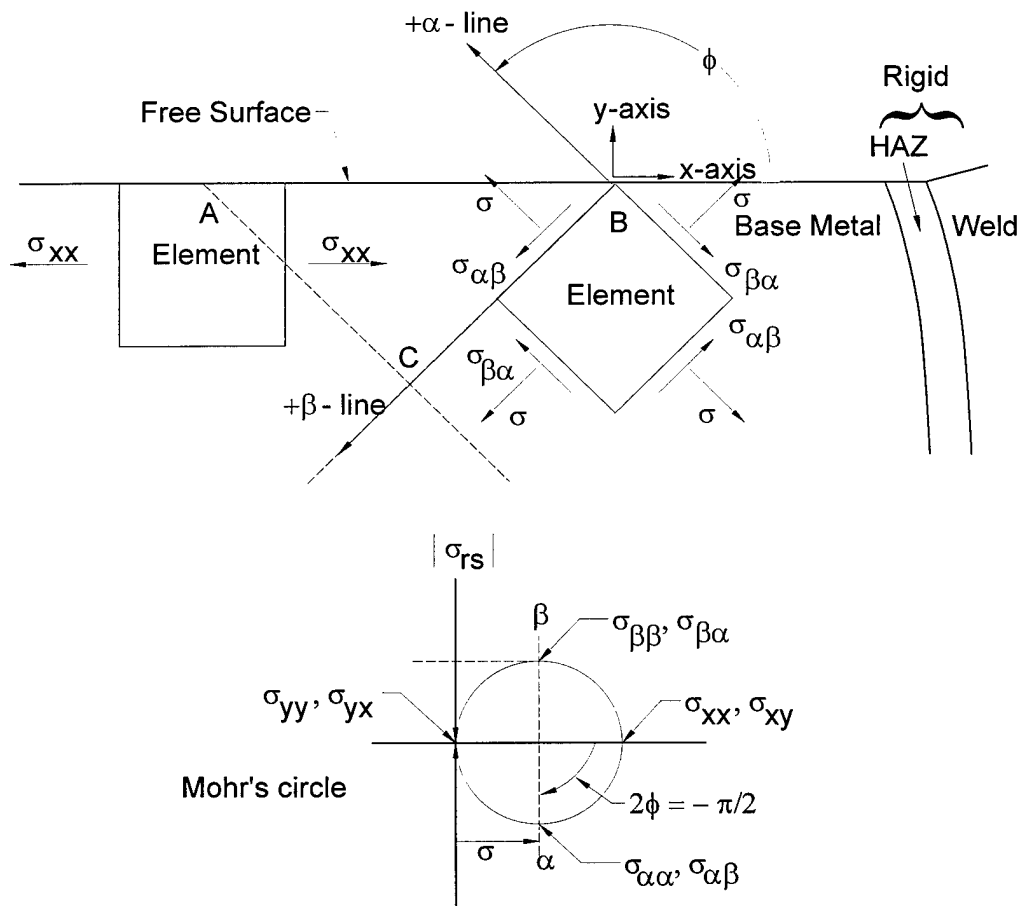


Figure 7. Element orientation on free surface.

In the x-direction stress, $\sigma_{xx}$, develops due to a far field tensile force and is given the value of 2k. Mohr's circle is also drawn in Figure 7 using these boundary conditions and reveals a maximum shear stress, k, at ±45° from the free surface. The radius of Mohr's circle is constant at k for this plane-strain non-hardening situation.

The orthogonal coordinates, shown in Figure 7, parallel to the planes of maximum shear and are called α-lines and β-lines. Along these two lines plastic flow, or slip, can take place. They are oriented such that the axis of maximum principle stress is 45° counter-clockwise from the α-line toward the β-line. This orientation will remain constant at these angles from the free surface throughout this analysis. The angle counter-clockwise from the x-axis to the α slip line is denoted by $\phi$.

The Cartesian components of stress are:

$$\sigma_{xx} = \sigma - k\sin2\phi \qquad (1a)$$

$$\sigma_{yy} = \sigma + k\sin2\phi \qquad (1b)$$

$$\sigma_{xy} = k\cos2\phi \qquad (1c)$$

where $\sigma_{xx}$ and $\sigma_{yy}$ are the normal stresses, $\sigma_{xy}$ is the shear stress, $\sigma$ is the mean normal stress.

Along the two slip lines, the in-plane partial differential equations of equilibrium become:

$$\text{Along an α-line, } d\sigma = 2k\,d\phi \qquad \text{and} \qquad (2)$$

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$$\text{along a }\beta\text{-line, } d\sigma = -2k\, d\phi. \qquad\qquad (3)$$

Integrating inward along an $\alpha$-line from point A to point C yields,

$$\sigma_C - \sigma_A = 2k(\phi_C - \phi_A). \qquad\qquad (4)$$

Since the angle, $\phi$, at both point A and C is 45° counter-clockwise from the x-axis and constant, the stress at point C, $\sigma_C$, is equal to the stress at point A, $\sigma_A$. Similarly, integrating inward from point B to point C along a $\beta$-line yields,

$$\sigma_C - \sigma_B = -2k(\phi_C - \phi_B). \qquad\qquad (5)$$

Again, $\phi$ is constant resulting in the stresses at points B and C, $\sigma_B$ and $\sigma_C$ respectively, being equal. When this processes is repeated to additional points into the material, the same results are found. It is also discovered that when reaching the bottom free surface the signs of the stresses are reversed. Performing this process starting from the bottom free surface yields the same sign discontinuity when reaching the top surface. It is clear there are two active slip line fields that approach a neutral axis.

Considering the overall equilibrium, applying a displacement, u, to the plate ends, a far field tensile force, P, operates through the center of the weld (see Figure 8). Summing the forces in the x-direction and moments about point O, yields Equations (6) and (7) respectively. Assuming the width (recall Figure 3) of the plate to be unity, and setting both of them equal to zero to satisfy equilibrium:

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$$\sum F_x = -P + 2k(h - y_{na}) - 2ky_{na} = 0 \qquad (6)$$

$$\sum M_o = -P \left(\frac{1}{2} h + y_p - y_{na}\right) + \frac{1}{2} 2ky^2_{na} + \frac{1}{2} 2k(h - y_{na})^2 = 0 \qquad (7)$$

where 2k is the yield stress of the metal, h is the thickness of the plate, $y_{na}$ is the position of

the neutral axis from the bottom surface, and $y_p$ is the distance of the offset from the applied

tensile force, P, to the center of the cross-section of the plate.
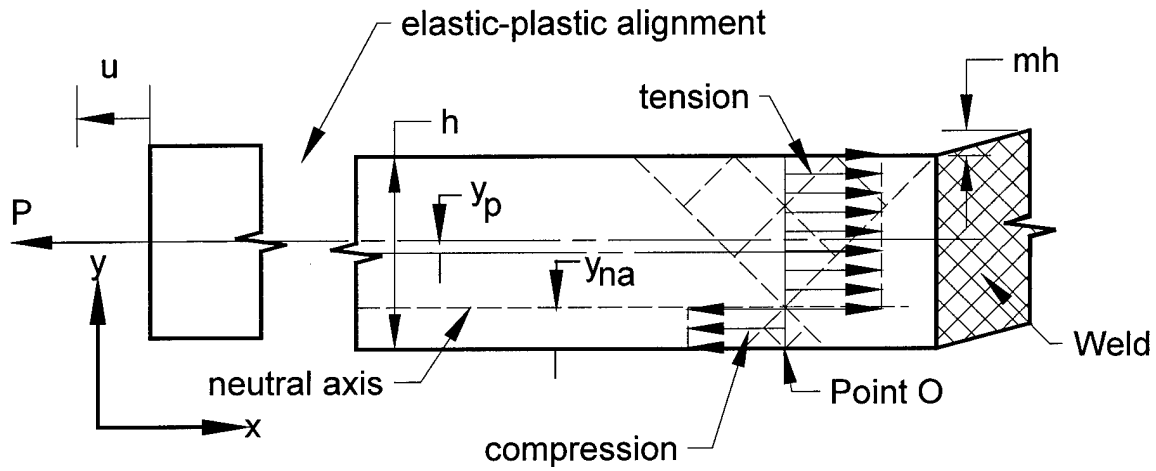


Figure 8. Free-body diagram of weldment. (Cross-sectional view)

Expanding and substituting Equation (6) into Equation (7) yields Equation (8), a

solution for the position of the neutral axis as a function of the plate offset, m. Figure 9

shows the relationship.

$$y_{na} = \frac{1}{2} (h + 4mh - \sqrt{h^2 + 16m^2 h^2}) \qquad (8)$$

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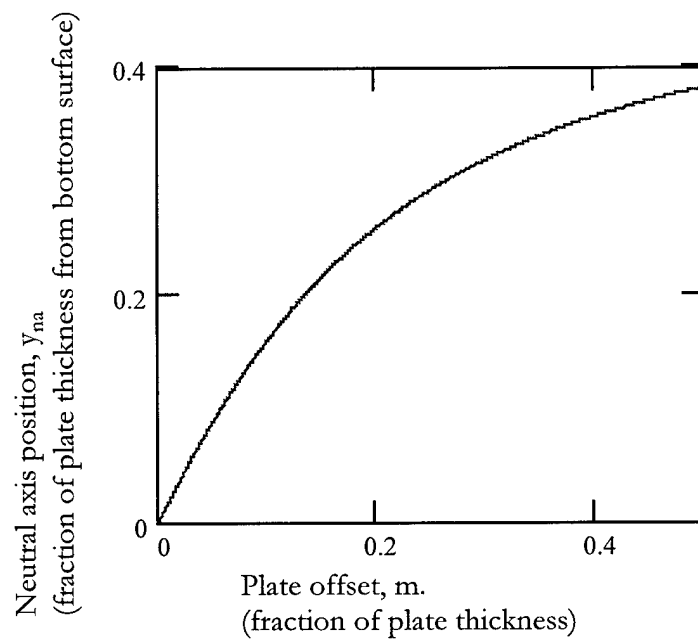
Figure 9.  Neutral axis position as a function of plate offset.

The displacement increments, or "velocities" in terms of a fictitious time, are denoted $u_\alpha$ and $u_\beta$ along the $\alpha$-lines and $\beta$-lines respectively and shown in Figure 10.
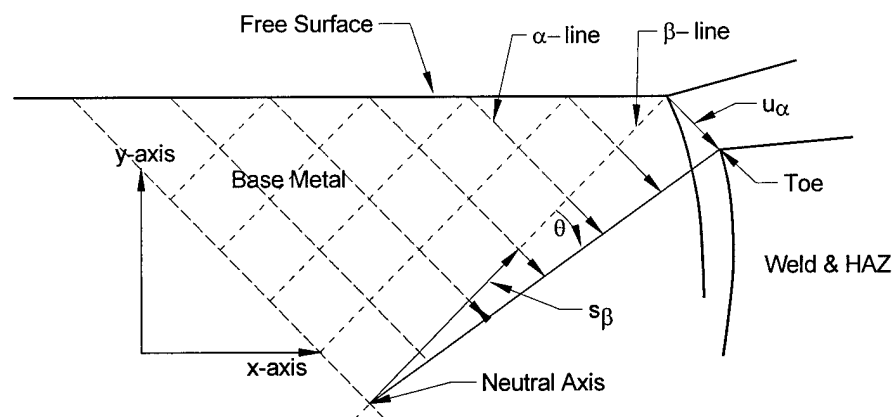


Figure 10.  Displacements along $\alpha$ and $\beta$-lines.

The partial differential equations of incompressibility lead to:

Along an $\alpha$-line;

$$du_\alpha = u_\beta \, d\phi \qquad \text{and} \qquad (9)$$

along a $\beta$-line;

$$du_\beta = -u_\alpha \, d\phi. \qquad (10)$$

Shear discontinuities are possible across an $\alpha$-line (along a $\beta$-line) so there is no limit to the change in $u_\alpha$. Similarly, across a $\beta$-line, $u_\beta$ can change discontinuously.

Knowing $\phi$ is a constant,

$$d\phi = 0. \qquad (11)$$

This yields from equation (9),

$$du_\alpha = 0. \qquad (12)$$

Therefore along an $\alpha$-line $u_\alpha$ is a constant and has a solution;

$$u_\alpha = s_\beta \, \theta \qquad (13)$$

where $s_\beta$ is the distance along a $\beta$-line and $\theta$ is the small, displaced angle of the $\beta$-line.

Recalling equation (10), along a β-line:

$$du_\beta = -u_\alpha \, d\phi. \qquad\qquad (10)$$

Applying the boundary condition that the toe of the weld is rigid due to its higher hardness, at the end of the β-line shown in Figure 10, no change in length is allowed so,

$$u_\beta = 0. \qquad\qquad (14)$$

Therefore, there is no displacement, $u_\beta$, along any β-line. This conclusion will be used during the graphical solution to give insight into the deformation and failure mechanisms of the welded plates in question.

# Chapter 4 Graphical Integration

## 4.1 Application of slip line field theory

DELTACAD® software is employed for improved accuracy to the graphical

solution. The line of action of the applied external force P, imposes a moment that rotates

the weld. This removes some of the offset, shifting the neutral axis down, and causing the

resulting stress components along the rigid body interface closer to a line of action through

the center of the weld. Figure 11 shows the initial geometry of a plate with 15% of the plate

thickness offset.
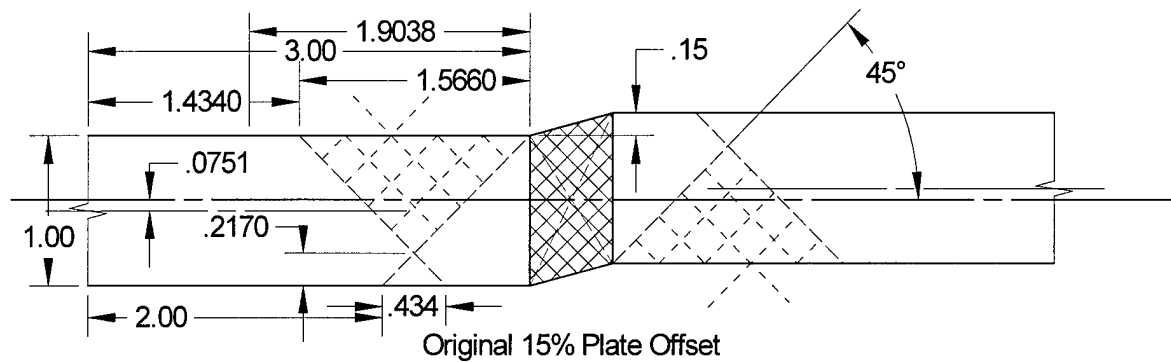
Figure 11. Initial weldment geometry (dimensions in cm).

The crosshatched area is the weld and a region of rigidity. The dashed lines indicate slip line fields (α-lines and β-lines). Choosing weld rotation as the variable, increments of 1 degree are sequentially mechanically imposed to the weld with the center of the weld fixed. The upper triangle is in tension and slip occurs along the α-lines only. The lower triangle is in compression and again slip only occurs along the α-lines. Solving Equations (9) and (10) with the applied boundary conditions yields the quasi-static rigid body shapes as seen in Figure 12. Applying a displacement, u, to the far field end of the plate, a tensile force develops. This moves rigid body E to the left and upwards with no rotation. A hinge at point F imposes a rotation on rigid body D about its center.
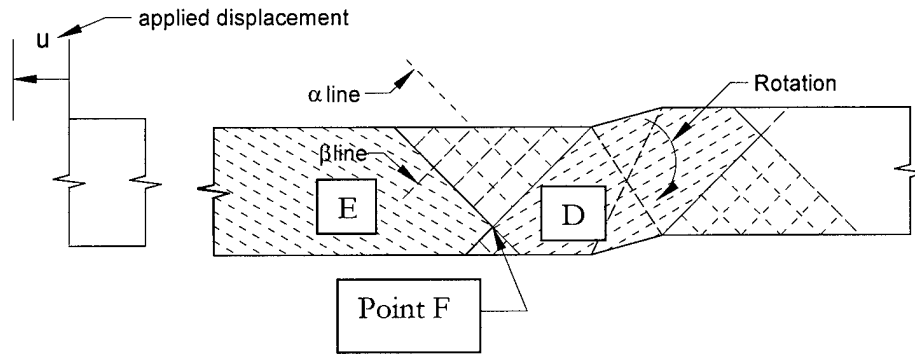
Figure 12. Rigid body rotation mechanics.

The same phenomenon is mirrored and upside down on the other side of the weld. Each incremental rotation causes the offset to become less while the neutral axis moves toward the lower surface. Note: It is recognized that fans of slip line fields will arise as the body deforms. The shape assumed for rigid body D during this analysis is driven by the solution derived in chapter 3. Again, the only rigid region of rigid body D is the weld itself. All other regions of rigid body D are free to deform. This treatment is considered a good upper bound approximation.

Figures 13 shows a representative sequence of events required when the weld is rotated 1 degree clockwise. It is assumed the deforming top and bottom surfaces remain straight. However, since the neutral axis is shifting down, the affected top surface becomes longer, resulting in a small curved section at the left end of the slip line field shown. This affect is considered small and negligible.
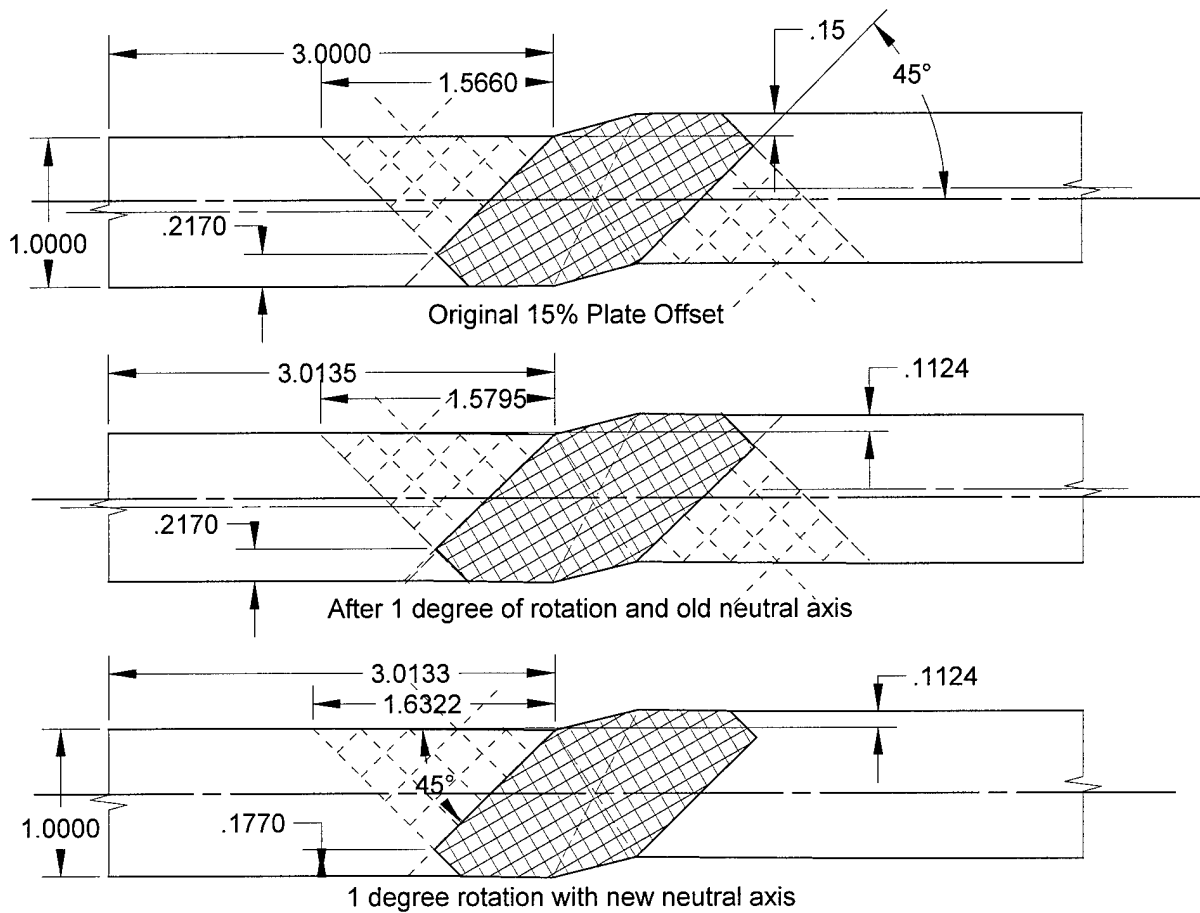
Figure 13.  Sequence for 1 degree clockwise weld rotation.


Figure 14 shows the weldment after about 4 degrees of clockwise rotation.  The offset is removed.

3.2989

1.9342

1.00

Misalignment Removed

.9656

4 degrees of rotation and new neutral axis
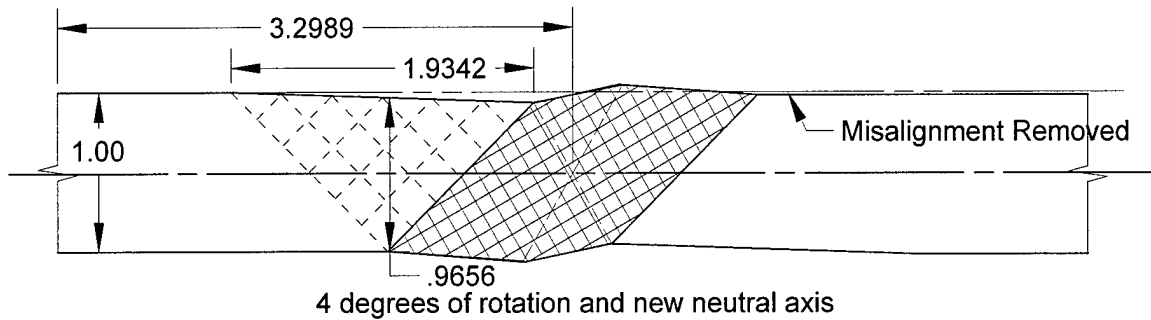
Figure 14. Weldment rotation to remove offset.

It is evident that some thinning occurs in the region next to the weld. However, the resulting stresses acting on the interface between the slip line field and the weld are not yet in equilibrium. The center of the slip line face in the slip field is lower than the center of the weld. Further rotation of the weld is necessary to reach equilibrium as Figure 15 shows.



3.3153

1.9503

1.00

45°

.9540

6° rotation to align weld center to center of slip line face
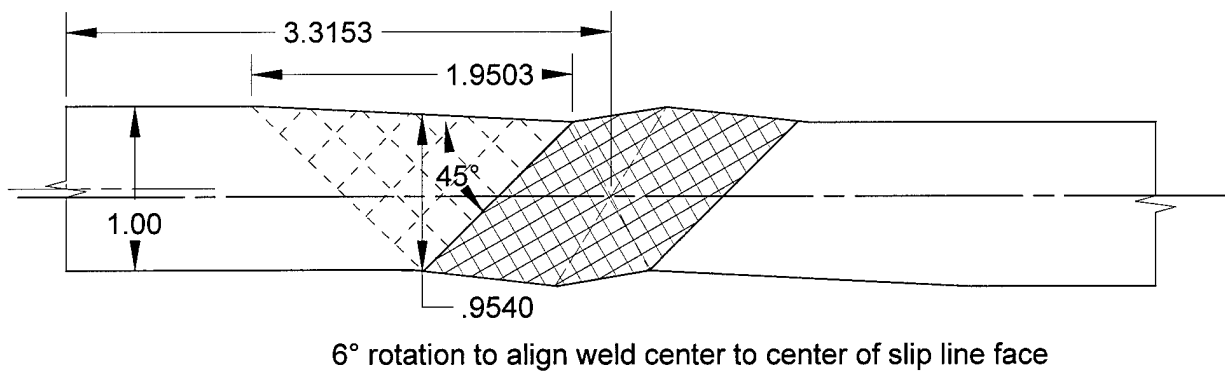
Figure 15. Weldment rotation to equilibrium.

At this angle of weld rotation, about 6 degrees clockwise, the resulting stresses on the interface plane between the slip line plane and rigid body D act through the center of the weld. The plastic strains observed along the top surface in the x-direction ($\varepsilon_{xx}$) are

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displayed in Table 2 and graphed in Figure 16. A linear trend line was added using the method of least squares to smooth out the results of the graphical approach.

Table 2. Calculated strains as a fraction of plate thickness per degree of clockwise rotation of rigid weld.

| Weld Rotation (degrees CW) | Calculated strain (incremental $\varepsilon_i$) |
|---|---|
| 1 | 0.00683 |
| 2 | 0.00706 |
| 3 | 0.00737 |
| 4 | 0.00778 |
| 6 | 0.00815 |

This amount of plastic strain is believed to lead to a shear band emanating from the toe of the weld down to the bottom surface at about a 135 degree clockwise angle from the x-axis. Shearing off of this surface cannot happen until the neutral axis vanishes and the entire cross section is experiencing tension promoting this shear band. The addition, summed up by Equation (14), of all the plastic strains observed while applying slip line field theory and rigid body kinematics along the top surface next to the weld is 0.037 or 3.7%.

$$\varepsilon = \sum_{i=1}^{6} \varepsilon_i = 0.037 \qquad\qquad (14)$$

**Top Surface Strains vs Rotation**
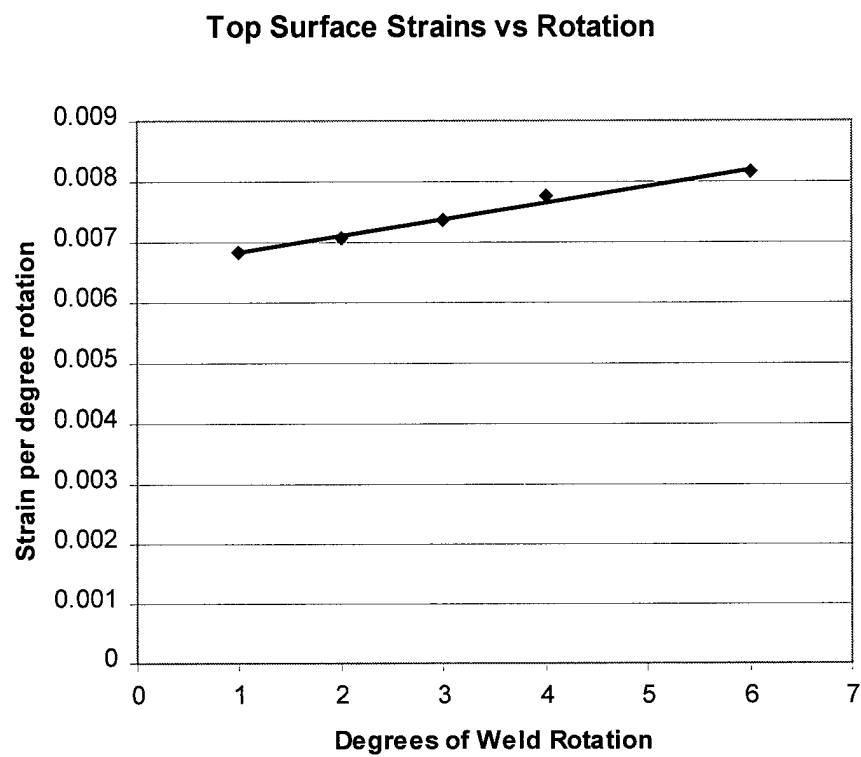
Figure 16. Top surface strain increments per degree of clockwise weld rotation.

# Chapter 5 Finite elements

## 5.1 Finite Element Approach

In addition to the slip line field solution based on a rigid-perfectly plastic model, Teng (2001) [13] conducted finite element analysis. The following properties of the base metal and weld metal were assumed:

Base metal-     Modulus of Elasticity, E =200,000 MPa

Upper Yield Point, UYP = 200 MPa

Poisons ratio, $v = 0.48$

Weld metal-     Modulus of Elasticity, E =200,000 MPa

Upper Yield Point, UYP = 260 MPa

Poisons ratio, $v = 0.48$.

These values were chosen to mimic a rigid-perfectly plastic, nearly incompressible, model. A displacement was applied at each end of the model while the center of the weld was fixed. Figure 17 shows the mesh selected in the region of the offset. A mesh density of twenty elements through the thickness was used for the weld and adjacent regions. To reduce the CPU time, the mesh density was lowered to ten and then six elements through the thickness at 5 and 10 plate thicknesses away from the center, respectively. This mesh is sufficiently fine enough to capture the expected compression zone near the weld. The output from ABACUS[®], Figure 18, shows the plastic strain in the x-direction, pe11, resulting from a displacement imposed at the plates free ends corresponding to the strain required to induce plasticity of 0.03 compared to the elastic strain of 0.003. The position of neutral axes are clearly visible. An additional displacement was applied to induce a plastic strain of 0.1. The slip line field is evident as the triangular regions in Figure 19. The entire cross-section in now in tension, forming a shear band from the toe of the weld and extending to the bottom surface at approximately a 135 degree clockwise angle from the positive x-axis.
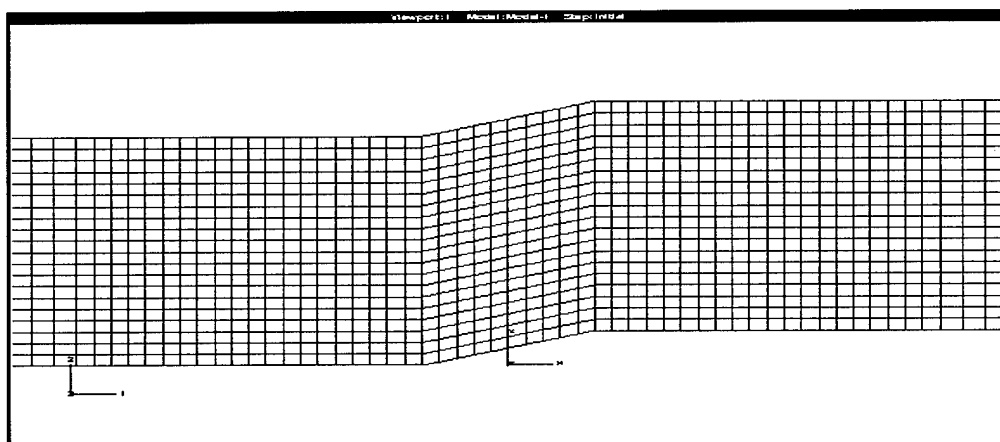
Figure 17. ABAQUS® mesh of offset plates [13].

Figure 18. ABAQUS® displacement to onset of plasticity [13].
Edges of bands correspond to pe11 = -0.01 (0.007) +0.07
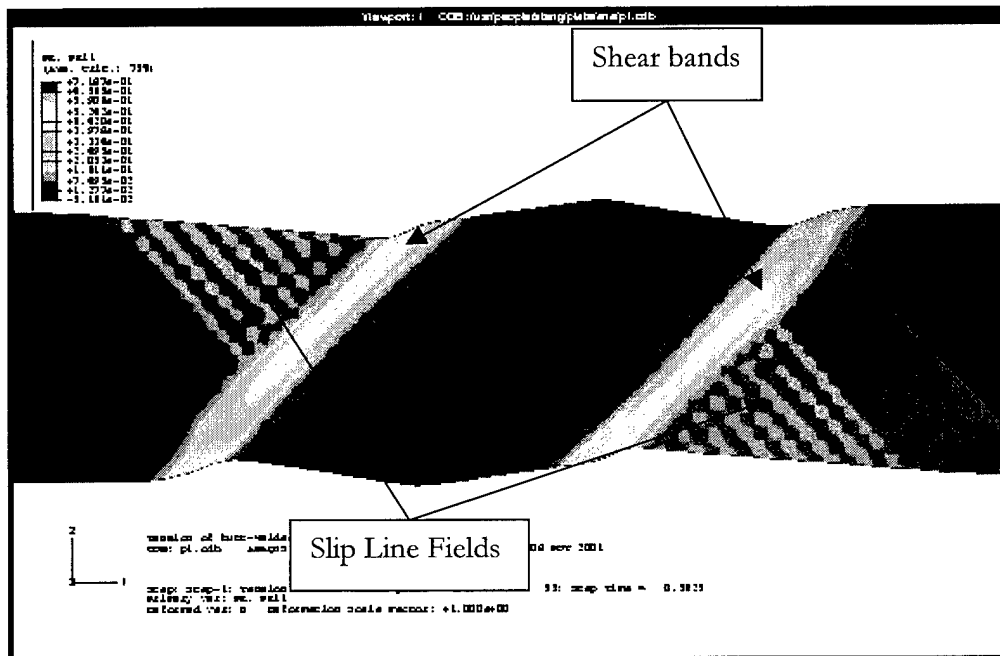
Figure 19. ABAQUS® showing slip line fields and shear bands [13].

Edges of bands correspond to pe11 = -0.001 (0.05) +0.7(Deformation exaggerated).

# Chapter 6 Experiments

## 6.1 Specimen design

In order to verify the results obtained from applying slip line field theory, it is necessary to design, build, and test specimens to observe the predicted phenomena. American Society of Test Mechanics, (ASTM), (2000) [14] does not specifically address how to design a test specimen for this particular application. Therefore, the flat tensile test specimen was used as guidance. It was necessary to determine the proper dimensions to ensure the testing machine was kept within its limitations. Appendix A shows the detailed calculations given the properties of EH-36 [9].

It was also necessary to carefully design the specimen utilizing existing test fixtures and jigs in order to mimic the effect of a far field tensile force being applied through the center of the weld for the duration of the test. Figure 20 shows the detailed geometry of the test specimen. It is believed the removed material (machined out region) on each side of the simulated weld keeps the tensile force, applied by the machine grips, acting through the center of the weld. Figure 21 shows a close-up view of the line of action of the applied force, P. A flush "dog-bone" test specimen, one with no offset, was used to verify the

material property data provided for EH-36 [9] and for subsequent input into ABACUS® for

finite element analysis.
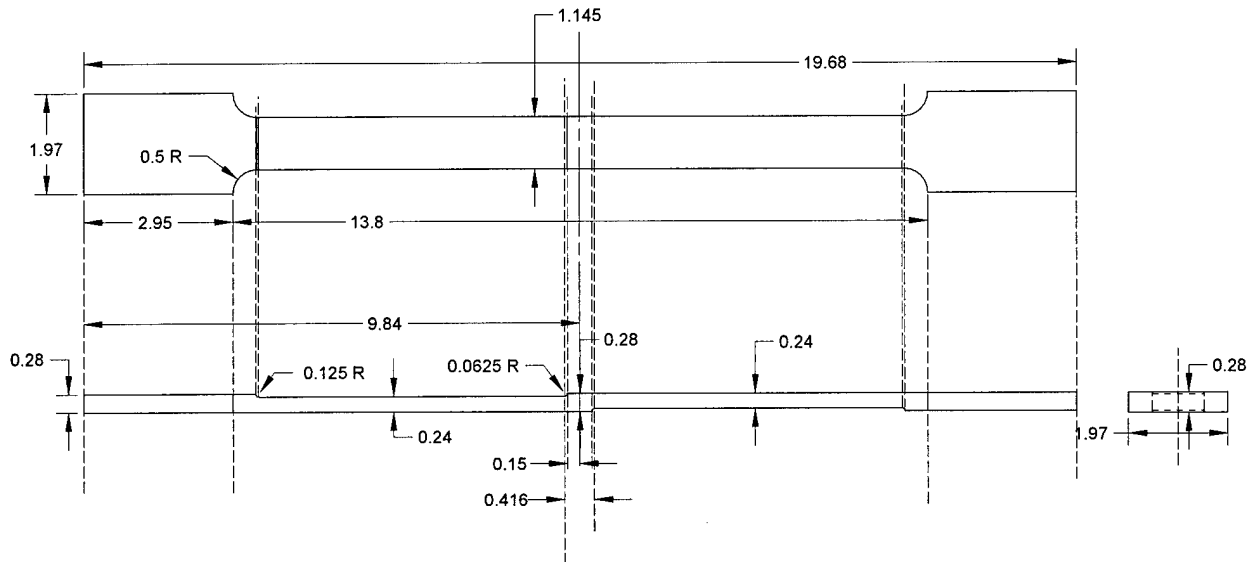


Figure 20.  16.7% offset test specimen drawing (dimensions in inches).
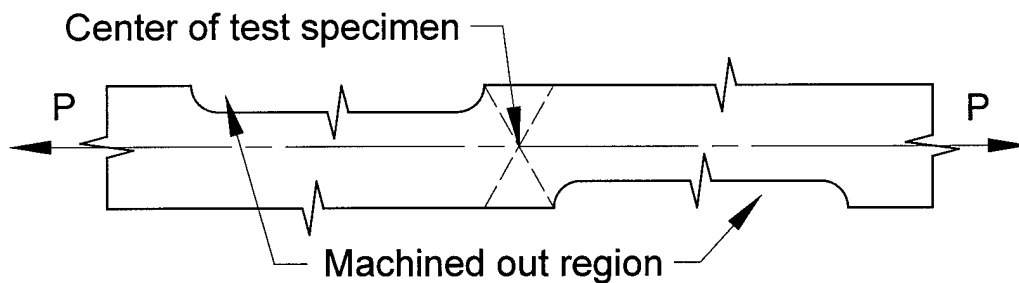


Figure 21.  Cross-section of offset specimen showing the line of action.
(Not drawn to scale).

Actual welding of the test specimen was not performed because only the verification

of slip line field theory was the phenomena that wanted to be studied at this point.  It is

believed welding adds complexities and uncertainties unwanted at this phase of analysis. The predicted slip lines are still believed to be observable due to the fact the mid-section of the specimen is thicker and more massive than the adjacent machined out plates. Therefore, less stress and lower strains will be felt in the mid-section imitating a hard, rigid weld. Tests on welded plates with various degree of offset will be performed as a continuation of this research.

## 6.2 Testing procedure and apparatus

A MTS Model RF/200 floor standing testing machine was used to test the two specimens. First, the flat plate "dog-bone" specimen was placed vertically into the opposing grips. It was fitted with one extensometer near the midsection and the other extensometer on the same side in the top half of the specimen (see Figure 22). A steady displacement rate of 0.02 in/sec was applied to the top grip. The force on the load cell and the extensions were measured and recorded electronically. At maximum load, the extension was stopped and the upper extensometer was placed nearest the location of suspected failure to obtain a truer strain at failure. The extensometers were set-up to have a maximum extension of 0.2 inches or 50% strain.

The second test piece was machined as a "dog-bone" specimen with a 16.7% offset and the same thickness as the first specimen. Again, two extensometers were used (see Figure 23). One was placed next to the simulated weld on the tensile side on the upper half of the specimen within the expected active slip line field, while the other extensometer was placed on the same side approximately one-third of the way down from the top grip. To better view the results, the displacement rate applied to the top grip was slowed to

approximately 0.003 in/sec. Once necking was observed elsewhere the uni-axial stress was insufficient load to deform the specimen around the weld, the test was stopped.
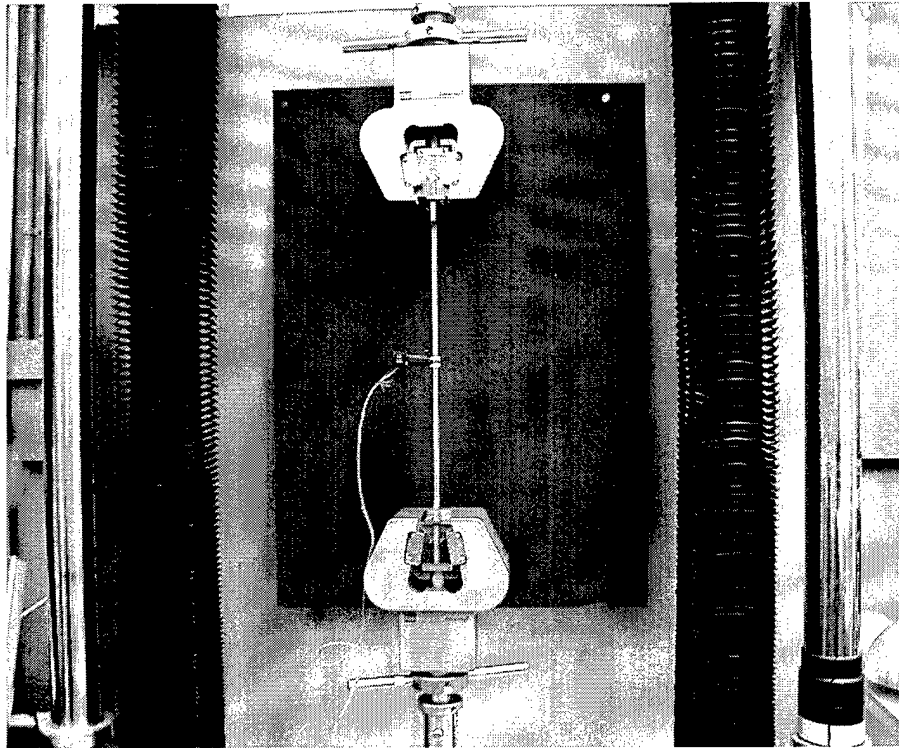


Figure 22. Test set-up of flat plate specimen. (Only one extensometer shown).
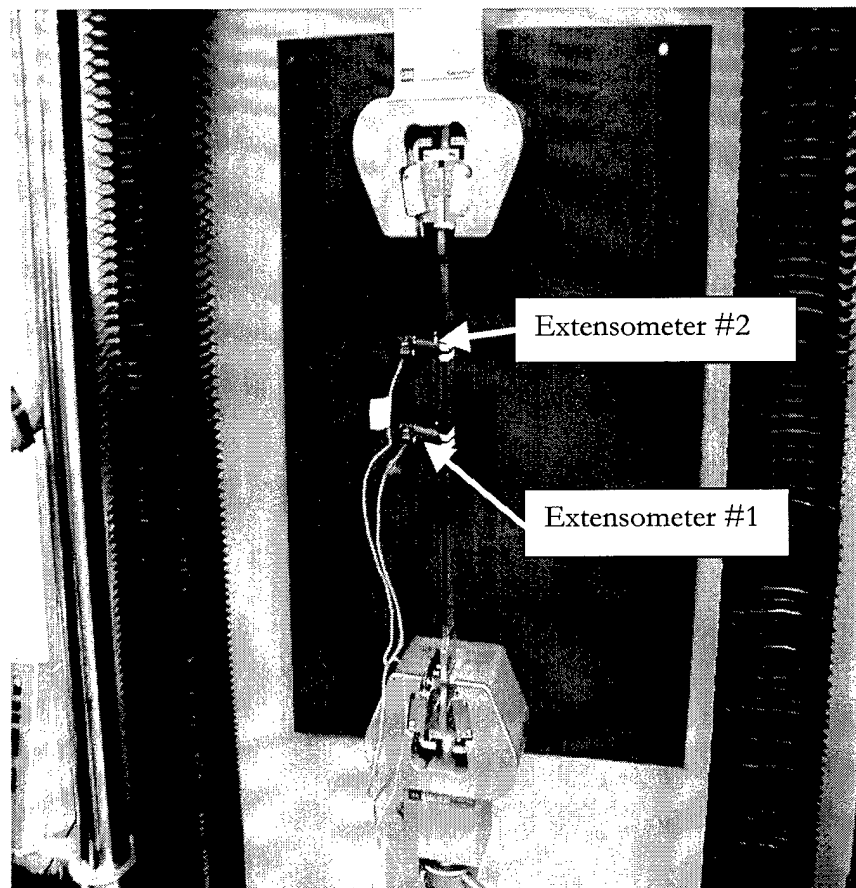
Figure 23. 16.7% offset test specimen set-up.

# Chapter 7 Analysis of test data

## 7.1 Results

The flat plate specimen exhibited typical mild steel properties. Figure 24 shows the stress-strain curve obtained for the tensile test. Appendix B contains the recorded data. Table 3 summarizes the material behavior of the flat plate tensile specimen pulled to failure. The discontinuity in the data is due to stopping the test and repositioning the second extensometer on the observed necking. At this point the first extensometer returns to its plastic strain value as its stress in unloaded.

Since the flat plate specimen failed at half the machine capacity, plane-strain conditions for the offset specimen would only require $\frac{2}{\sqrt{3}}$, or 15% greater load, well within the testing machine specifications.

Flat Plate Stress-Strain Curve
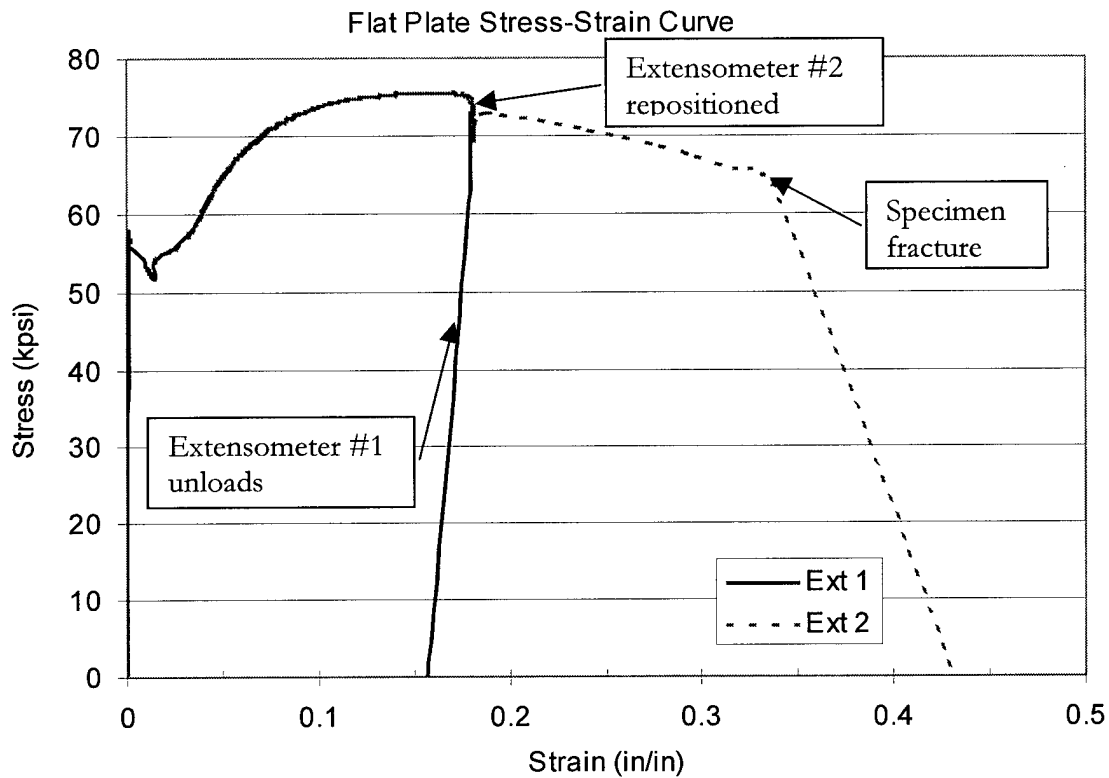


Figure 24. Stress-strain curve for the flat plate "dog-bone" specimen.

Table 3. Summary of observed properties of EH-36 specimens.

| Property | Flat Plate Specimen | 16.7% Offset Specimen |
|---|---|---|
| Upper Yield Point, UYP | 56.6 kpsi | 55.6 kpsi |
| Modulus of Elasticity, E | $34.5 \times 10^6$ psi | $49.1 \times 10^6$ psi |
| Tensile Strength, TS | 75.5 kpsi | 75.3 kpsi |
| Strain to Necking | 0.157 | 0.155 |
| Strain to Failure $\{\ln (A_o/A)\}$ | 1.07 | not observed |

Table 3 also shows the material properties of the offset specimen compared to the initial flat plate specimen, while Figure 25 shows the stress-strain curve for the offset specimen. Appendix C contains the recorded data.
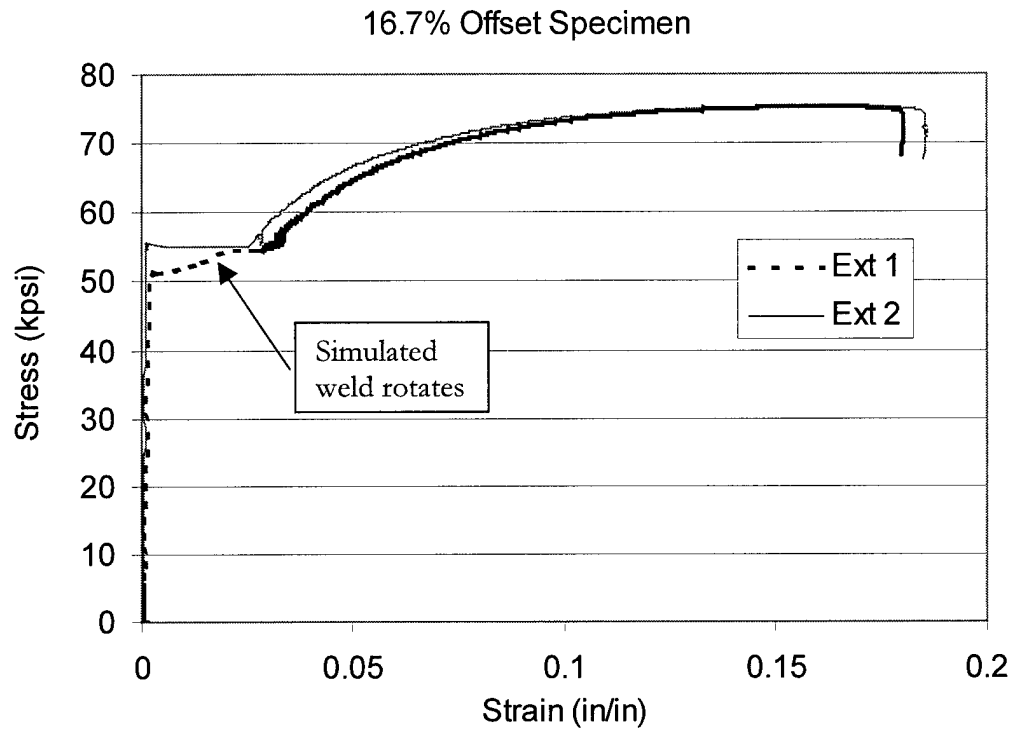
Figure 25. Stress-strain curve for specimen with 16.7% offset.

It was observed during testing of the offset specimen the simulated rigid weld region rotated as the material yielded (see Figure 26). The bend and thinning around the weld were insufficient to maintain plane-strain conditions. Post test measurements reveal the following comparisons summarized in Table 4. The simulated weld rotation, amount of strain, and the reduction in the plate thickness observed agrees with that predicted using slip line field theory.
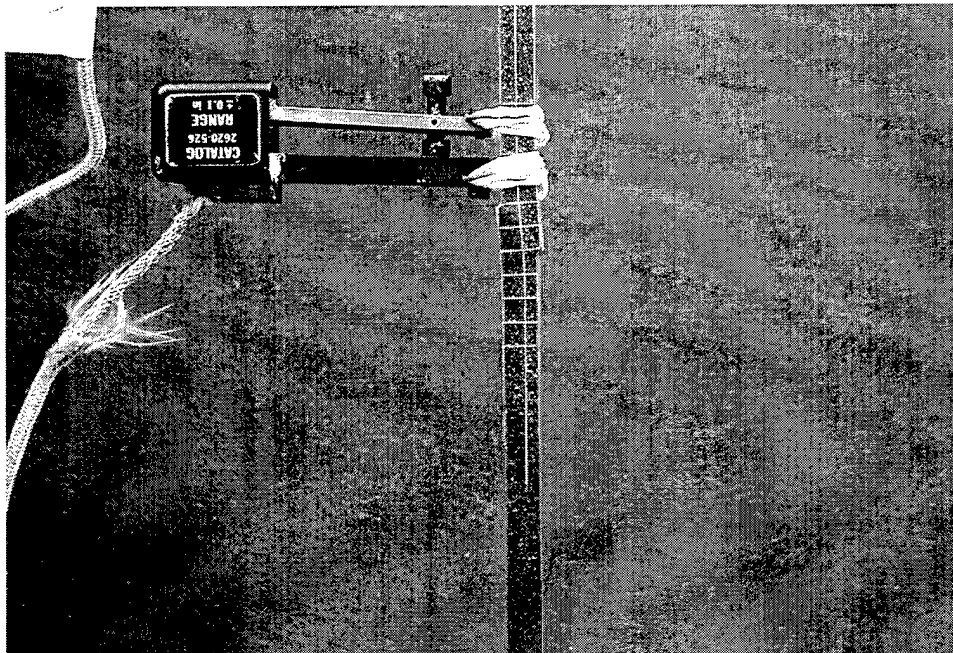
Figure 26. 16.7% offset specimen rotation.

Table 4. Comparison of test results to slip line field theory predictions.

| Parameter | Slip Line Field Theory Prediction | Test Results |
|---|---|---|
| Simulated Weld region Rotation | 4-6 degrees | 4 degrees |
| Fraction of plate thickness reduction next to simulated weld region | 0.046 | 0.07-0.104 |
| Fractional strain on top surface next to simulated weld region | 0.0303 | 0.03 |

## 7.2 Conclusions

Slip line field theory is a good tool to use in predicting the deformation and rigid body motions near an offset weld. Since the rotation of the simulated offset weld occurred in the lower yield region, it corresponded to slip line field theory. The assumption of plane-strain was not valid for the offset test specimen with a width-to-thickness ratio of 4. This led to the offset specimen necking away from the anticipated active slip field after rotation. Thus, the expected shearing fracture from the toe of the weld was not observed. One cannot ensure that for plane-strain service conditions the 16.7% offset would not diminish the strength. This conclusion should be revisited by testing additional specimens with shoulders to promote more nearly plane-strain and with much sharper transition regions (i.e. smaller fillet radii) to simulate the HAZ.

## 7.3 Recommendations for Further Study

This study should continue with actual welded specimens by a qualified shipyard with plain-strain and with the maximum offsets allowed by military standards [7]. Data recorded for the material behavior of EH-36 should be incorporated into ABAQUS® along with fracture criteria for more accurate finite element analysis. To facilitate the plane-strain condition assumed in slip line field theory, test specimens should have a width-to-thickness ratio of 10 in to the welded region while being wider elsewhere. Additionally, more detailed weldment hardness profiles should be conducted to capture the hardness gradient in the

HAZ. This may lead to a smaller fillet radius in the simulated weld to better model the hardness gradient.

Preliminary analysis for bending parallel to the weld shows no strain or stress enhancements and is believed to be of little consequence. However, bending along the length of the weld may introduce higher strains and should be explored.

Finally, a differential geometry solution should be sought that could be integrated for an approximate closed form solution.

# Bibliography

[1]  USS DONALD COOK (DDG-75) website,
     http://www.spear.navy.mil/ships/ddg75, Mar01.

[2]  Snelling, William A. (1946) "Direct Explosion Test for Welded Armor and Ship
     Plate: Prime and Welded Plate Tests", Ship Structure Committee Report 4.

[3]  Davis, Harmer E., G. E. Troxell, earl R. Parker and A. Boodberg (1948)
     "Investigations of Brittle Cleavage Fracture of Welded Flat Plate by means of a Bend
     Test", Ship Structure Committee Report 6.

[4]  Dexter, R. J., E. B. Norris, W. R. Schick and P. D. Watson (1986) "Performance of
     Underwater Weldments", Ship Structure Committee Report 335.

[5]  Nguyen, T. Ninh, M. A. Wahab (1998) "The effect of weld geometry and residual
     stresses on the fatigue of welded joints under combined loading", Journal of
     Materials Processing Technology 77, pp. 201-208.

[6]  Cui, Weicheng, Zhengquan Wan and Alla E. Mansour (1999) "Steel concentration
     factor in plates with transverse butt-weld misalignment", Journal of Construction
     Steel Research 52, pp. 159-170.

[7]  MIL-STD-1689A(SH), Chapter 12, Table XIX.

[8]  Forrest, David (2001), personal correspondence, BIW.

[9]  Konkol, Paul J., Kenneth M. Sabo, Gerard P. Mercier, Keith R. Miller, Frederick D.
     Arnold (2000) "Evaluation of Forming, Flame Bending, and Welding of ABS Grade
     EH-36 Steel Plates", National Center for Excellence in Metalworking Technology,
     Limited distribution.

[10] Shames, Irving H. (1989) "Introduction to Solid Mechanics", Prentice-Hall.

[11] AVONDALE DRW No. C6-017 29-01-10 sheet 4 of 6.

[12] Masubuchi, Koichi and R.G. Morris (2000) "A Welding Research and Engineering
     Festschrift", MIT Press.

[13] Teng, Xiaoging (2001) "Numerical Simulation of Effects of Mismatch and Misfit on
     Response of Butt-welded Plates", MIT Impact and Crashworthyness Laboratory,
     Report #52.

[14] ASTM (2000), Vol. 03.01, pp80.

# Appendix A  Specimen calculations

Specimen dimension calculations for flat specimen:

Given:

Tensile Strength, TS of EH-36

$$TS = 78 \text{ kpsi}$$

MTS test machine rating of 200 kN (44961 lbs).

Design to use only one-half of MTS machine rating, F.

$$TS = \frac{P}{A}$$

$$A = wt$$

where A is the area, w is the specimen width, and t is the specimen thickness.

Solving for P,

$$P = A(TS) = (1.14 \text{ in})(0.24 \text{ in})(78000 \text{ lbs/in}^2)$$

$$P = 21340 \text{ lbs.}$$

$$\frac{P}{F} = \frac{21340 \text{ lbs}}{44961 \text{ lbs}} = 0.47$$

Thus the force, P, required to break the specimen is approximately one-half of the capability of the machine.

# Appendix B Flat plate specimen test data

Calibration Data:

Load channel (5000 lbs/volt)
Extensometer #1, fc = 34.1192 in/volt/volt
Extensometer #2, fc = 32.0252 in/volt/volt
Gage length = 0.4 in

Calculations:

P = Load(5000 lbs/volt)

$$\text{Extension (in)} = \frac{fc}{\text{Input volts}}(\text{Ext 1 output volts})$$

$$\text{Strain} = \frac{\text{Extension}}{0.4}$$

Recorded Data

| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 1.21 | 0.012273 | 0.014064 | 3.99216 | 0.0329 |
| 2.96 | 0.012269 | 0.014069 | 3.99214 | 0.0329 |
| 122.42 | 0.013246 | 0.014035 | 4.00391 | 0.0377 |
| 124.17 | 0.013256 | 0.01403 | 4.00391 | 0.0377 |
| 125.89 | 0.01326 | 0.014019 | 4.00391 | 0.0377 |
| 127.64 | 0.013272 | 0.01403 | 4.0039 | 0.0377 |
| 129.34 | 0.013263 | 0.014028 | 4.0039 | 0.0377 |
| 131.09 | 0.01326 | 0.014028 | 4.0039 | 0.0377 |
| 132.8 | 0.013241 | 0.014019 | 4.00388 | 0.0377 |
| 162.25 | 0.013279 | 0.014045 | 4.00389 | 0.0377 |
| 164 | 0.013267 | 0.014045 | 4.00387 | 0.0377 |
| 165.75 | 0.013265 | 0.014047 | 4.00385 | 0.0377 |
| 167.46 | 0.013253 | 0.014052 | 4.00383 | 0.0279 |
| 169.21 | 0.013232 | 0.014042 | 4.00379 | 0.028 |
| 170.92 | 0.013232 | 0.014047 | 4.0037 | 0.2614 |
| 172.67 | 0.013217 | 0.014042 | 4.00349 | 0.6858 |
| 174.39 | 0.013232 | 0.014057 | 4.00316 | 1.1209 |
| 176.14 | 0.01322 | 0.014061 | 4.00267 | 1.6003 |
| 177.84 | 0.013172 | 0.014057 | 4.00211 | 2.074 |
| 179.59 | 0.013194 | 0.014057 | 4.00145 | 2.5722 |
| 181.3 | 0.013179 | 0.014069 | 4.00071 | 3.0241 |
| 183.05 | 0.013151 | 0.014047 | 3.99991 | 3.1109 |
| 184.76 | 0.013139 | 0.014035 | 3.99908 | 3.1049 |
| 186.51 | 0.013153 | 0.014052 | 3.99826 | 3.0992 |
| 188.23 | 0.013151 | 0.014052 | 3.99752 | 3.1465 |
| 189.98 | 0.013151 | 0.014057 | 3.99668 | 3.1137 |
| 191.68 | 0.013163 | 0.014047 | 3.99585 | 3.0829 |
| 193.44 | 0.013153 | 0.014057 | 3.99508 | 3.0685 |
| 195.19 | 0.013141 | 0.014052 | 3.99434 | 3.0952 |
| 196.91 | 0.013155 | 0.014057 | 3.99374 | 3.1041 |
| 198.66 | 0.013155 | 0.014057 | 3.99326 | 3.0969 |
| 200.37 | 0.013153 | 0.014047 | 3.99293 | 3.1644 |
| 202.12 | 0.013148 | 0.014069 | 3.99265 | 3.089 |
| 203.82 | 0.013141 | 0.014057 | 3.9925 | 3.1063 |
| 205.57 | 0.013158 | 0.01404 | 3.99226 | 3.0989 |
| 207.28 | 0.013155 | 0.014047 | 3.99213 | 3.0708 |
| 209.03 | 0.013165 | 0.014057 | 3.99212 | 3.0612 |
| 210.75 | 0.013175 | 0.014071 | 3.99215 | 3.0427 |
| 212.5 | 0.013158 | 0.014069 | 3.9922 | 3.0463 |

| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 214.21 | 0.01316 | 0.014061 | 3.99223 | 3.0539 |
| 215.96 | 0.013151 | 0.014061 | 3.99227 | 3.0513 |
| 219.41 | 0.012724 | 0.014057 | 3.99249 | 2.9197 |
| 221.12 | 0.012695 | 0.014061 | 3.99247 | 2.9083 |
| 222.89 | 0.012686 | 0.014061 | 3.99235 | 2.9003 |
| 224.64 | 0.012681 | 0.014066 | 3.99225 | 2.8953 |
| 226.34 | 0.012643 | 0.014066 | 3.99219 | 2.8904 |
| 228.09 | 0.01266 | 0.014071 | 3.99216 | 2.8855 |
| 229.8 | 0.012643 | 0.014057 | 3.9922 | 2.8807 |
| 231.55 | 0.012633 | 0.014045 | 3.99218 | 2.8772 |
| 233.26 | 0.012633 | 0.014061 | 3.99223 | 2.8758 |
| 235.01 | 0.012629 | 0.014061 | 3.99236 | 2.8727 |
| 236.73 | 0.012629 | 0.014057 | 3.9924 | 2.8709 |
| 238.48 | 0.012629 | 0.014057 | 3.99232 | 2.8709 |
| 240.18 | 0.012609 | 0.014061 | 3.99212 | 2.8661 |
| 241.93 | 0.012602 | 0.014057 | 3.99215 | 2.8661 |
| 243.64 | 0.0126 | 0.014052 | 3.99218 | 2.8661 |
| 245.39 | 0.0126 | 0.014052 | 3.99219 | 2.8612 |
| 247.1 | 0.012595 | 0.014057 | 3.99215 | 2.8612 |
| 248.87 | 0.012578 | 0.014064 | 3.99215 | 2.8612 |
| 250.62 | 0.012588 | 0.014057 | 3.99225 | 2.8612 |
| 252.32 | 0.012583 | 0.014061 | 3.99223 | 2.8574 |
| 254.07 | 0.012574 | 0.014076 | 3.99233 | 2.8563 |
| 255.78 | 0.012576 | 0.014057 | 3.99225 | 2.8563 |
| 257.53 | 0.012564 | 0.014052 | 3.99223 | 2.8563 |
| 259.25 | 0.012569 | 0.014057 | 3.99225 | 2.8563 |
| 261 | 0.012581 | 0.014061 | 3.99226 | 2.8563 |
| 262.71 | 0.012574 | 0.014061 | 3.99223 | 2.8514 |
| 319.32 | 0.012516 | 0.014052 | 3.99214 | 2.8368 |
| 321.03 | 0.012514 | 0.014057 | 3.99211 | 2.9619 |
| 322.78 | 0.012032 | 0.014042 | 3.9921 | 3.0479 |
| 324.5 | 0.01162 | 0.01404 | 3.9922 | 3.156 |
| 326.25 | 0.011506 | 0.014052 | 3.99223 | 3.2137 |
| 328 | 0.011439 | 0.014047 | 3.99224 | 3.2488 |
| 329.71 | 0.011365 | 0.014057 | 3.99227 | 3.2769 |
| 331.46 | 0.011336 | 0.014047 | 3.99223 | 3.3045 |
| 333.17 | 0.011301 | 0.014047 | 3.99218 | 3.3288 |
| 334.92 | 0.011246 | 0.014047 | 3.99217 | 3.3539 |
| 336.64 | 0.011198 | 0.014057 | 3.99217 | 3.3775 |
| 338.39 | 0.011165 | 0.014045 | 3.9921 | 3.4005 |
| 340.09 | 0.011112 | 0.014047 | 3.99213 | 3.4218 |
| 341.84 | 0.011067 | 0.014061 | 3.9921 | 3.4433 |
| 343.55 | 0.011026 | 0.014064 | 3.99211 | 3.4636 |
| 345.3 | 0.010986 | 0.014042 | 3.99211 | 3.4844 |
| 347.01 | 0.010943 | 0.014045 | 3.99215 | 3.5032 |
| 348.76 | 0.010893 | 0.014047 | 3.99215 | 3.5211 |
| 350.48 | 0.010867 | 0.014057 | 3.99218 | 3.5389 |
| 352.23 | 0.010812 | 0.014052 | 3.99219 | 3.5574 |
| 353.93 | 0.010781 | 0.014052 | 3.99214 | 3.5729 |
| 355.69 | 0.010728 | 0.014061 | 3.99206 | 3.5902 |
| 357.44 | 0.010688 | 0.014057 | 3.99205 | 3.6072 |
| 359.16 | 0.01064 | 0.014045 | 3.99215 | 3.6218 |
| 360.91 | 0.010588 | 0.014045 | 3.99219 | 3.6364 |
| 362.62 | 0.010561 | 0.014061 | 3.99216 | 3.651 |
| 364.37 | 0.010511 | 0.014052 | 3.99214 | 3.6656 |
| 366.07 | 0.010473 | 0.014052 | 3.99221 | 3.6786 |
| 367.82 | 0.010428 | 0.014047 | 3.99217 | 3.691 |
| 369.53 | 0.010397 | 0.014061 | 3.99221 | 3.7047 |
| 371.28 | 0.010349 | 0.014061 | 3.99231 | 3.7187 |
| 373 | 0.010299 | 0.014047 | 3.99238 | 3.7289 |
| 374.75 | 0.010247 | 0.014042 | 3.99232 | 3.7436 |
| 376.46 | 0.010218 | 0.014057 | 3.9923 | 3.7533 |
| 378.21 | 0.010175 | 0.014057 | 3.99233 | 3.7653 |
| 379.91 | 0.010111 | 0.014038 | 3.99233 | 3.7777 |
| 381.66 | 0.010087 | 0.014047 | 3.9923 | 3.7874 |
| 383.37 | 0.010046 | 0.014057 | 3.99227 | 3.7972 |
| 385.14 | 0.009999 | 0.014052 | 3.99216 | 3.8069 |
| 386.89 | 0.009946 | 0.014047 | 3.99217 | 3.8166 |
| 388.59 | 0.009913 | 0.014047 | 3.99216 | 3.8265 |

| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 390.34 | 0.009849 | 0.014047 | 3.99216 | 3.8362 |
| 392.05 | 0.009829 | 0.014052 | 3.99214 | 3.8459 |
| 395.51 | 0.009737 | 0.014052 | 3.99218 | 3.8654 |
| 397.26 | 0.009686 | 0.014045 | 3.99213 | 3.8726 |
| 398.98 | 0.009658 | 0.014047 | 3.99213 | 3.88 |
| 400.73 | 0.009624 | 0.014052 | 3.9921 | 3.8897 |
| 402.43 | 0.009558 | 0.014057 | 3.99206 | 3.896 |
| 404.18 | 0.009515 | 0.014061 | 3.99208 | 3.9044 |
| 405.89 | 0.009467 | 0.014052 | 3.99211 | 3.9127 |
| 407.64 | 0.009417 | 0.014061 | 3.99214 | 3.9191 |
| 409.35 | 0.009398 | 0.014064 | 3.99217 | 3.9261 |
| 411.1 | 0.009341 | 0.014061 | 3.9922 | 3.9337 |
| 412.82 | 0.009288 | 0.014057 | 3.99221 | 3.9386 |
| 414.57 | 0.009262 | 0.014057 | 3.99216 | 3.948 |
| 416.32 | 0.009207 | 0.014057 | 3.9922 | 3.9532 |
| 418.03 | 0.009155 | 0.014052 | 3.99222 | 3.9581 |
| 419.78 | 0.009105 | 0.014061 | 3.99225 | 3.9632 |
| 421.5 | 0.009064 | 0.014045 | 3.99229 | 3.9725 |
| 423.25 | 0.009009 | 0.014066 | 3.99225 | 3.9776 |
| 424.96 | 0.008978 | 0.014045 | 3.99227 | 3.9824 |
| 426.71 | 0.008921 | 0.01404 | 3.9923 | 3.9873 |
| 428.41 | 0.008885 | 0.014061 | 3.9923 | 3.9922 |
| 430.16 | 0.00884 | 0.014038 | 3.9923 | 3.9971 |
| 431.87 | 0.0088 | 0.014057 | 3.99221 | 4.0019 |
| 433.62 | 0.008745 | 0.01403 | 3.99214 | 4.0068 |
| 435.33 | 0.008711 | 0.01404 | 3.99215 | 4.0117 |
| 437.08 | 0.008664 | 0.014047 | 3.9922 | 4.0166 |
| 438.8 | 0.008623 | 0.01403 | 3.99218 | 4.0214 |
| 440.55 | 0.008583 | 0.014066 | 3.99222 | 4.0263 |
| 442.3 | 0.008525 | 0.014052 | 3.99222 | 4.0309 |
| 444.01 | 0.008504 | 0.014069 | 3.99221 | 4.0331 |
| 445.76 | 0.008449 | 0.014061 | 3.99218 | 4.0361 |
| 447.48 | 0.008406 | 0.014066 | 3.99215 | 4.0409 |
| 449.23 | 0.008358 | 0.014076 | 3.99223 | 4.0458 |
| 450.93 | 0.008316 | 0.014061 | 3.99225 | 4.0498 |
| 452.68 | 0.008261 | 0.014057 | 3.9922 | 4.0507 |
| 454.39 | 0.008208 | 0.014057 | 3.99221 | 4.0556 |
| 456.14 | 0.008177 | 0.014061 | 3.99223 | 4.0605 |
| 457.85 | 0.008127 | 0.014052 | 3.99221 | 4.0605 |
| 459.6 | 0.00807 | 0.014047 | 3.99223 | 4.0654 |
| 461.32 | 0.008034 | 0.014047 | 3.99219 | 4.0662 |
| 463.07 | 0.008006 | 0.014052 | 3.9922 | 4.0703 |
| 464.77 | 0.007946 | 0.014057 | 3.99219 | 4.0752 |
| 466.52 | 0.007905 | 0.014052 | 3.99223 | 4.0752 |
| 468.23 | 0.007853 | 0.014052 | 3.99223 | 4.08 |
| 470 | 0.007801 | 0.014052 | 3.99227 | 4.08 |
| 471.75 | 0.007755 | 0.014061 | 3.99218 | 4.0849 |
| 473.46 | 0.007708 | 0.014066 | 3.99221 | 4.0849 |
| 475.21 | 0.007677 | 0.014064 | 3.99217 | 4.0898 |
| 476.91 | 0.007617 | 0.014057 | 3.99214 | 4.0898 |
| 478.66 | 0.007579 | 0.014052 | 3.99217 | 4.0947 |
| 480.37 | 0.007526 | 0.014052 | 3.99217 | 4.0947 |
| 482.12 | 0.007472 | 0.014057 | 3.99215 | 4.0947 |
| 483.83 | 0.007431 | 0.014052 | 3.99212 | 4.0995 |
| 485.58 | 0.007383 | 0.014052 | 3.99215 | 4.0995 |
| 487.3 | 0.007336 | 0.014047 | 3.99221 | 4.1044 |
| 489.05 | 0.007286 | 0.01404 | 3.99221 | 4.1044 |
| 490.75 | 0.00724 | 0.014057 | 3.99224 | 4.1044 |
| 492.5 | 0.007205 | 0.014052 | 3.99221 | 4.1091 |
| 494.21 | 0.00715 | 0.014066 | 3.99219 | 4.1093 |
| 495.96 | 0.007107 | 0.014061 | 3.99225 | 4.1093 |
| 497.67 | 0.007052 | 0.014045 | 3.99226 | 4.1092 |
| 499.43 | 0.006999 | 0.014061 | 3.99225 | 4.1141 |
| 501.18 | 0.006949 | 0.014045 | 3.99229 | 4.1141 |
| 502.89 | 0.006904 | 0.014057 | 3.99224 | 4.1141 |
| 504.64 | 0.006861 | 0.014069 | 3.99218 | 4.1148 |
| 506.35 | 0.006823 | 0.014057 | 3.99217 | 4.1189 |
| 508.1 | 0.006752 | 0.014057 | 3.99217 | 4.1189 |
| 509.82 | 0.006723 | 0.014052 | 3.99215 | 4.1189 |

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| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 511.57 | 0.006673 | 0.014047 | 3.99214 | 4.1189 |
| 513.27 | 0.006613 | 0.014057 | 3.99217 | 4.119 |
| 516.73 | 0.00652 | 0.014047 | 3.99209 | 4.1238 |
| 518.48 | 0.006461 | 0.014038 | 3.99212 | 4.1238 |
| 520.19 | 0.00642 | 0.014057 | 3.99213 | 4.1238 |
| 521.94 | 0.006384 | 0.014061 | 3.9921 | 4.1238 |
| 523.66 | 0.006339 | 0.014045 | 3.9921 | 4.1238 |
| 525.41 | 0.006287 | 0.014061 | 3.99208 | 4.1238 |
| 527.12 | 0.006237 | 0.014052 | 3.99209 | 4.1238 |
| 528.87 | 0.006186 | 0.014057 | 3.9921 | 4.1247 |
| 530.62 | 0.006129 | 0.014035 | 3.99207 | 4.1287 |
| 532.33 | 0.006086 | 0.014047 | 3.9921 | 4.1287 |
| 534.08 | 0.006036 | 0.014061 | 3.99215 | 4.1287 |
| 535.8 | 0.005986 | 0.014052 | 3.99215 | 4.1287 |
| 537.55 | 0.005931 | 0.014057 | 3.99211 | 4.1287 |
| 539.25 | 0.005881 | 0.014047 | 3.99212 | 4.1288 |
| 541 | 0.005819 | 0.014057 | 3.9921 | 4.1287 |
| 542.71 | 0.0058 | 0.014057 | 3.99218 | 4.1287 |
| 544.46 | 0.005736 | 0.014035 | 3.99215 | 4.1287 |
| 546.17 | 0.005691 | 0.014047 | 3.99214 | 4.1287 |
| 547.92 | 0.00564 | 0.014057 | 3.99208 | 4.1287 |
| 549.64 | 0.005605 | 0.014057 | 3.99212 | 4.1287 |
| 551.39 | 0.005555 | 0.014057 | 3.99211 | 4.1288 |
| 553.09 | 0.005514 | 0.014047 | 3.99209 | 4.1281 |
| 554.84 | 0.005457 | 0.014047 | 3.99213 | 4.1238 |
| 556.55 | 0.005419 | 0.014042 | 3.99208 | 4.1238 |
| 558.32 | 0.005388 | 0.014066 | 3.9921 | 4.1238 |
| 560.07 | 0.005335 | 0.014066 | 3.99203 | 4.1239 |
| 561.77 | 0.005295 | 0.014057 | 3.99204 | 4.1239 |
| 563.52 | 0.005249 | 0.014057 | 3.99207 | 4.1238 |
| 565.23 | 0.005209 | 0.014064 | 3.99209 | 4.1238 |
| 566.98 | 0.005156 | 0.014066 | 3.99213 | 4.119 |
| 568.69 | 0.00513 | 0.014052 | 3.99216 | 4.119 |
| 570.44 | 0.005078 | 0.014061 | 3.99213 | 4.119 |
| 572.16 | 0.00504 | 0.014069 | 3.99218 | 4.119 |
| 573.91 | 0.005018 | 0.014061 | 3.9922 | 4.1141 |
| 575.62 | 0.004978 | 0.014057 | 3.99216 | 4.1141 |
| 577.37 | 0.004925 | 0.014052 | 3.9922 | 4.1093 |
| 579.07 | 0.004906 | 0.014052 | 3.99217 | 4.1093 |
| 580.82 | 0.00487 | 0.014038 | 3.9921 | 4.1044 |
| 582.53 | 0.004842 | 0.014052 | 3.99218 | 4.1044 |
| 584.3 | 0.004825 | 0.014047 | 3.99222 | 4.0995 |
| 586.05 | 0.004808 | 0.01404 | 3.99229 | 4.0947 |
| 587.75 | 0.004785 | 0.014047 | 3.99233 | 4.0872 |
| 589.5 | 0.004751 | 0.014035 | 3.99231 | 4.08 |
| 591.21 | 0.004763 | 0.014045 | 3.99221 | 4.0703 |
| 592.96 | 0.004751 | 0.014035 | 3.99225 | 4.0572 |
| 594.67 | 0.004734 | 0.014033 | 3.99214 | 4.0426 |
| 596.42 | 0.004732 | 0.014028 | 3.99215 | 4.0246 |
| 598.14 | 0.00473 | 0.014028 | 3.99214 | 4.0029 |
| 599.89 | 0.00473 | 0.014026 | 3.99214 | 3.9781 |
| 601.59 | 0.004744 | 0.014047 | 3.99217 | 3.9498 |
| 603.34 | 0.004746 | 0.014026 | 3.99216 | 3.8539 |
| 605.05 | 0.004734 | 0.014042 | 3.99215 | 3.8289 |
| 606.8 | 0.004737 | 0.01403 | 3.99218 | 3.8166 |
| 608.51 | 0.004734 | 0.014035 | 3.99222 | 3.8117 |
| 610.26 | 0.004763 | 0.01404 | 3.9922 | 3.8069 |
| 830.19 | 0.004768 | 0.014004 | 3.99222 | 3.7923 |
| 831.94 | 0.00478 | 0.013999 | 3.99221 | 3.7923 |
| 833.66 | 0.004773 | 0.013999 | 3.9922 | 3.7923 |
| 835.41 | 0.004768 | 0.013988 | 3.99221 | 3.7923 |
| 837.12 | 0.004768 | 0.01399 | 3.99219 | 3.7923 |
| 838.87 | 0.004763 | 0.013995 | 3.99219 | 3.9027 |
| 840.57 | 0.004763 | 0.013628 | 3.99213 | 3.9905 |
| 842.33 | 0.004758 | 0.012755 | 3.99219 | 3.9565 |
| 844.08 | 0.004756 | 0.011858 | 3.99217 | 3.9144 |
| 845.8 | 0.004773 | 0.010995 | 3.99214 | 3.8669 |
| 847.55 | 0.004763 | 0.010046 | 3.99213 | 3.811 |
| 849.25 | 0.004763 | 0.009145 | 3.99216 | 3.7496 |

| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 851 | 0.004768 | 0.008175 | 3.9921 | 3.677 |
| 852.71 | 0.004773 | 0.007238 | 3.99217 | 3.5948 |
| 859.64 | 0.005877 | 0.000355 | 3.99215 | -0.0364 |
| 861.39 | 0.006437 | 0.000355 | 3.99217 | -0.0364 |
| 863.09 | 0.006437 | 0.00035 | 3.99218 | -0.0364 |
| 864.84 | 0.006451 | 0.000369 | 3.99219 | -0.0364 |
| 866.55 | 0.006437 | 0.000352 | 3.99218 | -0.0364 |
| 868.3 | 0.006444 | 0.000369 | 3.99213 | -0.0364 |
| 873.52 | 0.006432 | 0.000364 | 3.99217 | -0.0364 |

# Appendix C Offset specimen test data

Calibration Data:

Load channel (5000 lbs/volt)
Extensometer #1, fc = 34.1192 in/volt/volt
Extensometer #2, fc = 32.0252 in/volt/volt
Gage length = 0.4 in

Calculations:

P = Load(5000 lbs/volt)

$$\text{Extension (in)} = \frac{fc}{\text{Input volts}}(\text{Ext 1 output volts})$$

$$\text{Strain} = \frac{\text{Extension}}{0.4}$$

Recorded Data:

| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|-----------|----------------------|----------------------|-------------|------|
| 1.2 | 0.013217 | 0.013761 | 4.003906 | -0.00218 |
| 2.96 | 0.013222 | 0.013775 | 4.003922 | -0.00219 |
| 226.18 | 0.013263 | 0.013861 | 4.003949 | -0.00216 |
| 227.93 | 0.013241 | 0.013849 | 4.003937 | -0.00217 |
| 229.64 | 0.013253 | 0.013854 | 4.003951 | -0.00217 |
| 231.39 | 0.013263 | 0.013854 | 4.003958 | -0.00217 |
| 233.1 | 0.013263 | 0.01384 | 4.003949 | -0.00218 |
| 234.85 | 0.013263 | 0.013842 | 4.003934 | -0.00216 |
| 236.57 | 0.013263 | 0.013854 | 4.003932 | -0.00216 |
| 238.32 | 0.013265 | 0.013856 | 4.003906 | -0.00217 |
| 240.02 | 0.013275 | 0.013856 | 4.003863 | -0.00216 |
| 241.77 | 0.013253 | 0.013847 | 4.003829 | 0.017788 |
| 243.48 | 0.013251 | 0.013847 | 4.003734 | 0.082209 |
| 245.23 | 0.013241 | 0.013849 | 4.003524 | 0.11095 |
| 246.94 | 0.013248 | 0.013852 | 4.003279 | 0.130031 |
| 248.69 | 0.013241 | 0.013837 | 4.002842 | 0.161688 |
| 250.41 | 0.013256 | 0.013852 | 4.002342 | 0.209863 |
| 252.16 | 0.013256 | 0.013837 | 4.001762 | 0.277712 |
| 253.86 | 0.013251 | 0.013825 | 4.001162 | 0.356678 |
| 255.62 | 0.013217 | 0.013828 | 4.000504 | 0.454463 |
| 257.37 | 0.013222 | 0.013823 | 3.999857 | 0.565941 |
| 259.08 | 0.013227 | 0.013823 | 3.99913 | 0.681235 |
| 260.83 | 0.013227 | 0.013825 | 3.998472 | 0.811829 |
| 262.54 | 0.01321 | 0.013818 | 3.997759 | 0.94171 |
| 264.29 | 0.013203 | 0.013811 | 3.997085 | 1.079328 |
| 266 | 0.013196 | 0.013804 | 3.996434 | 1.216325 |
| 267.75 | 0.013191 | 0.013799 | 3.99579 | 1.358799 |
| 269.46 | 0.013172 | 0.013785 | 3.995234 | 1.499643 |
| 271.21 | 0.01317 | 0.013799 | 3.994739 | 1.646707 |
| 272.92 | 0.013191 | 0.013804 | 3.994297 | 1.78797 |
| 274.67 | 0.013186 | 0.013799 | 3.993856 | 1.927692 |
| 276.39 | 0.01317 | 0.013775 | 3.993513 | 2.08522 |
| 278.14 | 0.013165 | 0.013775 | 3.993132 | 2.23839 |
| 279.84 | 0.013158 | 0.013775 | 3.992855 | 2.387971 |
| 281.59 | 0.013158 | 0.013761 | 3.992731 | 2.54446 |
| 283.3 | 0.013139 | 0.013761 | 3.992681 | 2.687487 |
| 285.07 | 0.013098 | 0.013763 | 3.9926 | 2.794835 |
| 286.82 | 0.01286 | 0.013759 | 3.992576 | 2.836821 |

| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 288.52 | 0.012547 | 0.013763 | 3.992545 | 2.899522 |
| 290.27 | 0.012383 | 0.013763 | 3.992536 | 2.962398 |
| 291.98 | 0.012192 | 0.013775 | 3.992536 | 2.990188 |
| 293.73 | 0.012028 | 0.013773 | 3.992559 | 2.99777 |
| 295.44 | 0.011932 | 0.013773 | 3.992486 | 3.002622 |
| 297.19 | 0.011863 | 0.013754 | 3.992438 | 3.01505 |
| 298.91 | 0.011842 | 0.013754 | 3.992426 | 3.03668 |
| 300.66 | 0.011839 | 0.013773 | 3.992402 | 3.041512 |
| 302.36 | 0.011844 | 0.013775 | 3.992366 | 3.031799 |
| 304.11 | 0.01183 | 0.013775 | 3.992304 | 3.017225 |
| 305.82 | 0.011823 | 0.013759 | 3.992295 | 3.019695 |
| 307.57 | 0.011816 | 0.013761 | 3.992264 | 3.007431 |
| 309.28 | 0.011827 | 0.013756 | 3.992278 | 3.009023 |
| 311.03 | 0.011813 | 0.013763 | 3.9923 | 3.013629 |
| 312.75 | 0.011818 | 0.013763 | 3.992278 | 3.017241 |
| 314.5 | 0.011811 | 0.013766 | 3.992321 | 3.017232 |
| 316.25 | 0.011804 | 0.013768 | 3.992326 | 3.022086 |
| 317.96 | 0.011806 | 0.013763 | 3.99235 | 3.017225 |
| 319.71 | 0.011801 | 0.013761 | 3.992376 | 3.017227 |
| 321.42 | 0.011799 | 0.013761 | 3.992424 | 3.027865 |
| 323.17 | 0.011813 | 0.013773 | 3.992431 | 3.031783 |
| 324.89 | 0.011787 | 0.013761 | 3.992452 | 3.037171 |
| 326.64 | 0.011789 | 0.013756 | 3.992316 | 3.036189 |
| 328.34 | 0.011789 | 0.013761 | 3.992316 | 3.018887 |
| 330.09 | 0.011792 | 0.013768 | 3.99228 | 3.024859 |
| 331.8 | 0.011808 | 0.01378 | 3.992309 | 3.040792 |
| 333.55 | 0.011777 | 0.013759 | 3.992397 | 3.046436 |
| 335.26 | 0.01178 | 0.013763 | 3.992443 | 3.051328 |
| 337.01 | 0.011785 | 0.013761 | 3.992383 | 3.051335 |
| 338.73 | 0.011763 | 0.013775 | 3.992397 | 3.05624 |
| 340.48 | 0.011763 | 0.013771 | 3.992352 | 3.059685 |
| 342.23 | 0.011763 | 0.01378 | 3.992381 | 3.051345 |
| 343.94 | 0.011773 | 0.013751 | 3.992373 | 3.041524 |
| 345.69 | 0.011758 | 0.013768 | 3.99234 | 3.041517 |
| 347.41 | 0.011763 | 0.013775 | 3.992302 | 3.046441 |
| 349.16 | 0.011763 | 0.013766 | 3.992285 | 3.05135 |
| 350.86 | 0.011768 | 0.013768 | 3.992342 | 3.06113 |
| 352.61 | 0.011761 | 0.01378 | 3.992362 | 3.065981 |
| 354.32 | 0.011758 | 0.013763 | 3.992328 | 3.05135 |
| 356.07 | 0.011737 | 0.013761 | 3.992326 | 3.038148 |
| 357.78 | 0.011758 | 0.01378 | 3.992402 | 3.035509 |
| 359.53 | 0.011751 | 0.013759 | 3.992359 | 3.056247 |
| 361.25 | 0.011734 | 0.013525 | 3.99229 | 3.027851 |
| 363 | 0.011744 | 0.013017 | 3.992269 | 3.022177 |
| 364.7 | 0.011742 | 0.012717 | 3.992269 | 3.028681 |
| 366.45 | 0.011725 | 0.012547 | 3.992249 | 3.022136 |
| 368.16 | 0.011737 | 0.012502 | 3.99229 | 3.053753 |
| 369.92 | 0.011746 | 0.012481 | 3.992269 | 3.082778 |
| 371.67 | 0.011734 | 0.012462 | 3.992269 | 3.109724 |
| 373.39 | 0.011718 | 0.012428 | 3.992261 | 3.119456 |
| 375.14 | 0.011708 | 0.012435 | 3.992288 | 3.113193 |
| 376.84 | 0.011696 | 0.012414 | 3.992319 | 3.100025 |
| 378.59 | 0.011696 | 0.012388 | 3.992345 | 3.114602 |
| 380.3 | 0.011689 | 0.0124 | 3.992357 | 3.117346 |
| 382.05 | 0.011661 | 0.012388 | 3.992285 | 3.105435 |
| 383.76 | 0.011665 | 0.012383 | 3.992264 | 3.066165 |
| 385.51 | 0.011687 | 0.012385 | 3.992247 | 3.063442 |
| 387.23 | 0.01167 | 0.012397 | 3.992247 | 3.061125 |
| 388.98 | 0.011675 | 0.012404 | 3.992247 | 3.046138 |
| 390.68 | 0.011672 | 0.012395 | 3.992238 | 3.073656 |
| 392.43 | 0.011684 | 0.012376 | 3.992247 | 3.139832 |
| 394.14 | 0.011651 | 0.012376 | 3.992216 | 3.163416 |
| 395.89 | 0.011639 | 0.012362 | 3.992216 | 3.17811 |
| 397.6 | 0.011615 | 0.01234 | 3.992197 | 3.190329 |
| 399.36 | 0.011591 | 0.012321 | 3.992173 | 3.202443 |
| 401.11 | 0.011568 | 0.012316 | 3.992176 | 3.215327 |
| 402.82 | 0.011539 | 0.01229 | 3.992199 | 3.226866 |
| 404.57 | 0.011522 | 0.01228 | 3.992271 | 3.236629 |
| 406.28 | 0.011491 | 0.012249 | 3.992397 | 3.247778 |

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| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 408.03 | 0.011465 | 0.012247 | 3.992304 | 3.256404 |
| 409.75 | 0.011446 | 0.012223 | 3.992362 | 3.265798 |
| 411.5 | 0.011446 | 0.012207 | 3.9924 | 3.275513 |
| 413.2 | 0.011425 | 0.012185 | 3.992319 | 3.283138 |
| 414.95 | 0.011401 | 0.012185 | 3.992273 | 3.290994 |
| 416.66 | 0.011398 | 0.01218 | 3.992304 | 3.301181 |
| 418.41 | 0.01137 | 0.012147 | 3.99228 | 3.313684 |
| 420.12 | 0.011367 | 0.012121 | 3.992285 | 3.324291 |
| 421.87 | 0.011365 | 0.012102 | 3.992311 | 3.334136 |
| 423.58 | 0.011329 | 0.012083 | 3.992264 | 3.343851 |
| 425.33 | 0.011327 | 0.01209 | 3.992278 | 3.353576 |
| 427.04 | 0.011303 | 0.012059 | 3.992271 | 3.363049 |
| 428.8 | 0.011281 | 0.01204 | 3.992261 | 3.373146 |
| 430.55 | 0.011258 | 0.012021 | 3.992321 | 3.381774 |
| 432.26 | 0.011239 | 0.011999 | 3.992311 | 3.389668 |
| 434.01 | 0.011212 | 0.011987 | 3.992333 | 3.398287 |
| 435.73 | 0.0112 | 0.011961 | 3.99228 | 3.407218 |
| 437.48 | 0.011179 | 0.011947 | 3.992264 | 3.416926 |
| 439.18 | 0.011184 | 0.011937 | 3.992333 | 3.42669 |
| 440.93 | 0.011155 | 0.011906 | 3.992311 | 3.43651 |
| 442.64 | 0.011146 | 0.011897 | 3.992328 | 3.441915 |
| 444.39 | 0.011117 | 0.01187 | 3.992321 | 3.451209 |
| 446.1 | 0.0111 | 0.011851 | 3.992302 | 3.460903 |
| 447.85 | 0.011072 | 0.011825 | 3.992309 | 3.469321 |
| 449.57 | 0.011062 | 0.011827 | 3.992352 | 3.475492 |
| 451.32 | 0.011053 | 0.011804 | 3.992342 | 3.485288 |
| 453.02 | 0.011022 | 0.011792 | 3.992471 | 3.492238 |
| 454.77 | 0.011014 | 0.011768 | 3.99244 | 3.499853 |
| 456.48 | 0.010986 | 0.011749 | 3.992443 | 3.509602 |
| 458.25 | 0.011 | 0.011732 | 3.992426 | 3.514511 |
| 460 | 0.010969 | 0.011718 | 3.992424 | 3.524324 |
| 461.7 | 0.010929 | 0.011699 | 3.9924 | 3.530366 |
| 463.45 | 0.010919 | 0.01167 | 3.992359 | 3.538899 |
| 465.16 | 0.010902 | 0.011656 | 3.992345 | 3.54428 |
| 466.91 | 0.01089 | 0.011634 | 3.992335 | 3.553459 |
| 468.62 | 0.010859 | 0.01162 | 3.992326 | 3.558685 |
| 470.37 | 0.01085 | 0.011591 | 3.992319 | 3.568131 |
| 472.08 | 0.01084 | 0.011577 | 3.992321 | 3.572945 |
| 473.83 | 0.010805 | 0.011563 | 3.992321 | 3.582644 |
| 475.54 | 0.01079 | 0.011541 | 3.992304 | 3.587591 |
| 477.29 | 0.010766 | 0.01151 | 3.992295 | 3.593239 |
| 479 | 0.010747 | 0.01151 | 3.992247 | 3.602352 |
| 480.75 | 0.010733 | 0.011496 | 3.992223 | 3.607208 |
| 482.46 | 0.010712 | 0.011477 | 3.992257 | 3.613412 |
| 484.23 | 0.010712 | 0.011451 | 3.99229 | 3.619229 |
| 485.98 | 0.010685 | 0.011439 | 3.992249 | 3.626701 |
| 487.68 | 0.010673 | 0.01142 | 3.992278 | 3.631503 |
| 489.43 | 0.010645 | 0.011394 | 3.992319 | 3.636386 |
| 491.14 | 0.010635 | 0.01137 | 3.992321 | 3.644356 |
| 492.89 | 0.010597 | 0.011346 | 3.992342 | 3.650979 |
| 494.6 | 0.010578 | 0.011329 | 3.99234 | 3.65585 |
| 496.35 | 0.010569 | 0.011327 | 3.992345 | 3.660757 |
| 498.07 | 0.010569 | 0.011308 | 3.99235 | 3.665692 |
| 499.82 | 0.010528 | 0.011281 | 3.992309 | 3.674721 |
| 501.52 | 0.010519 | 0.011277 | 3.992273 | 3.680329 |
| 503.27 | 0.010511 | 0.011243 | 3.992335 | 3.6852 |
| 504.98 | 0.010483 | 0.011231 | 3.992359 | 3.690016 |
| 506.73 | 0.010466 | 0.011196 | 3.992366 | 3.694899 |
| 508.44 | 0.010447 | 0.011184 | 3.992409 | 3.6998 |
| 510.19 | 0.010418 | 0.01116 | 3.992421 | 3.704695 |
| 511.91 | 0.010397 | 0.011141 | 3.992366 | 3.709998 |
| 513.66 | 0.010404 | 0.011136 | 3.992373 | 3.717706 |
| 515.41 | 0.010373 | 0.011105 | 3.99234 | 3.723318 |
| 517.12 | 0.010354 | 0.011096 | 3.992309 | 3.72895 |
| 518.87 | 0.010328 | 0.011055 | 3.992304 | 3.733854 |
| 520.58 | 0.010313 | 0.01105 | 3.992328 | 3.738741 |
| 522.33 | 0.010282 | 0.011019 | 3.992397 | 3.743605 |
| 524.04 | 0.010275 | 0.010993 | 3.992278 | 3.748159 |
| 525.79 | 0.010247 | 0.010964 | 3.992261 | 3.753108 |

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| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 527.5 | 0.010232 | 0.010943 | 3.992245 | 3.758196 |
| 529.25 | 0.010197 | 0.010917 | 3.99219 | 3.762898 |
| 530.96 | 0.010194 | 0.010898 | 3.992197 | 3.76661 |
| 532.71 | 0.010178 | 0.010886 | 3.99218 | 3.769845 |
| 534.42 | 0.010161 | 0.010859 | 3.992271 | 3.773231 |
| 536.17 | 0.010132 | 0.01085 | 3.992304 | 3.777709 |
| 537.89 | 0.010123 | 0.010819 | 3.992295 | 3.782579 |
| 539.64 | 0.010101 | 0.010809 | 3.992285 | 3.787384 |
| 541.34 | 0.010077 | 0.010783 | 3.992319 | 3.792278 |
| 543.1 | 0.010063 | 0.010762 | 3.992311 | 3.797183 |
| 544.85 | 0.010032 | 0.010743 | 3.992321 | 3.802058 |
| 546.57 | 0.010027 | 0.010719 | 3.992362 | 3.806881 |
| 548.32 | 0.010001 | 0.0107 | 3.992376 | 3.808653 |
| 550.02 | 0.009992 | 0.010683 | 3.992311 | 3.811757 |
| 551.77 | 0.009961 | 0.01065 | 3.9923 | 3.816645 |
| 553.48 | 0.009942 | 0.010635 | 3.992321 | 3.821516 |
| 555.23 | 0.009927 | 0.010621 | 3.992383 | 3.826403 |
| 556.94 | 0.009908 | 0.010592 | 3.992319 | 3.831298 |
| 558.69 | 0.009903 | 0.01059 | 3.99228 | 3.833556 |
| 560.41 | 0.009875 | 0.010566 | 3.992311 | 3.836219 |
| 562.16 | 0.009858 | 0.01055 | 3.992352 | 3.841102 |
| 563.86 | 0.009856 | 0.010523 | 3.992326 | 3.845908 |
| 565.61 | 0.009818 | 0.010478 | 3.992328 | 3.849718 |
| 567.32 | 0.00981 | 0.010468 | 3.992381 | 3.850796 |
| 569.07 | 0.009779 | 0.010466 | 3.992397 | 3.855733 |
| 570.78 | 0.009772 | 0.010447 | 3.992359 | 3.86058 |
| 572.54 | 0.009756 | 0.010404 | 3.992316 | 3.864889 |
| 574.29 | 0.009713 | 0.010383 | 3.992288 | 3.86537 |
| 576 | 0.00972 | 0.010354 | 3.992264 | 3.870267 |
| 577.75 | 0.009694 | 0.01034 | 3.99223 | 3.875169 |
| 579.46 | 0.009667 | 0.010321 | 3.992183 | 3.875498 |
| 581.21 | 0.009658 | 0.010311 | 3.99229 | 3.880052 |
| 582.92 | 0.009636 | 0.010306 | 3.992271 | 3.884866 |
| 584.67 | 0.009608 | 0.010273 | 3.992288 | 3.887503 |
| 586.39 | 0.009601 | 0.010242 | 3.992481 | 3.889763 |
| 588.14 | 0.009586 | 0.010232 | 3.992502 | 3.894636 |
| 589.84 | 0.009551 | 0.010216 | 3.992426 | 3.895962 |
| 591.59 | 0.009534 | 0.010197 | 3.992452 | 3.899505 |
| 593.3 | 0.009524 | 0.010192 | 3.99244 | 3.904423 |
| 595.05 | 0.009498 | 0.010144 | 3.992426 | 3.904442 |
| 596.76 | 0.009467 | 0.010132 | 3.992393 | 3.909349 |
| 598.52 | 0.009465 | 0.010106 | 3.992614 | 3.914239 |
| 600.27 | 0.009438 | 0.010077 | 3.992536 | 3.914253 |
| 601.98 | 0.009419 | 0.010068 | 3.992433 | 3.919138 |
| 603.73 | 0.009405 | 0.010054 | 3.992359 | 3.921666 |
| 605.44 | 0.009386 | 0.010018 | 3.992397 | 3.923957 |
| 607.19 | 0.009357 | 0.00998 | 3.992328 | 3.928811 |
| 608.91 | 0.009341 | 0.009992 | 3.992342 | 3.928821 |
| 610.66 | 0.009319 | 0.009961 | 3.992223 | 3.93372 |
| 612.36 | 0.009307 | 0.009949 | 3.992223 | 3.933875 |
| 614.11 | 0.009288 | 0.009918 | 3.992166 | 3.938605 |
| 615.82 | 0.009269 | 0.009906 | 3.992187 | 3.941507 |
| 617.57 | 0.009238 | 0.00988 | 3.992168 | 3.943409 |
| 619.28 | 0.009222 | 0.009872 | 3.992192 | 3.94814 |
| 621.03 | 0.009212 | 0.009841 | 3.992173 | 3.948285 |
| 622.75 | 0.009193 | 0.00981 | 3.992173 | 3.953175 |
| 624.5 | 0.009181 | 0.009799 | 3.992023 | 3.953189 |
| 626.2 | 0.009148 | 0.00977 | 3.991951 | 3.958058 |
| 627.96 | 0.009138 | 0.009753 | 3.992078 | 3.958072 |
| 629.71 | 0.009109 | 0.009737 | 3.992137 | 3.962891 |
| 631.42 | 0.009105 | 0.00971 | 3.992149 | 3.9629 |
| 633.17 | 0.009078 | 0.009698 | 3.992156 | 3.967759 |
| 634.89 | 0.009059 | 0.009679 | 3.992142 | 3.96779 |
| 636.64 | 0.009031 | 0.009675 | 3.992168 | 3.972644 |
| 638.34 | 0.009026 | 0.009648 | 3.992214 | 3.972687 |
| 640.09 | 0.009016 | 0.009629 | 3.992209 | 3.977551 |
| 641.8 | 0.008997 | 0.009613 | 3.992209 | 3.97757 |
| 643.55 | 0.008974 | 0.009591 | 3.992137 | 3.982441 |
| 645.26 | 0.008947 | 0.00957 | 3.992149 | 3.982424 |

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| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 647.01 | 0.008935 | 0.009543 | 3.99218 | 3.987178 |
| 648.73 | 0.008907 | 0.009531 | 3.992173 | 3.987343 |
| 650.48 | 0.008888 | 0.00951 | 3.992216 | 3.989598 |
| 652.18 | 0.008878 | 0.009477 | 3.992216 | 3.992221 |
| 653.93 | 0.008852 | 0.009458 | 3.992233 | 3.992223 |
| 655.64 | 0.008833 | 0.009438 | 3.992326 | 3.997123 |
| 657.41 | 0.008828 | 0.009436 | 3.992288 | 3.997128 |
| 659.16 | 0.008797 | 0.009403 | 3.992257 | 4.001908 |
| 660.86 | 0.00879 | 0.009369 | 3.992273 | 4.001932 |
| 662.61 | 0.008764 | 0.009377 | 3.992362 | 4.002571 |
| 664.32 | 0.00874 | 0.009357 | 3.992357 | 4.006817 |
| 666.07 | 0.008726 | 0.009326 | 3.99229 | 4.006843 |
| 667.78 | 0.008702 | 0.009295 | 3.99229 | 4.011721 |
| 669.53 | 0.008687 | 0.009293 | 3.992295 | 4.011752 |
| 671.25 | 0.008668 | 0.009269 | 3.99229 | 4.01369 |
| 673 | 0.008654 | 0.009255 | 3.992278 | 4.016599 |
| 674.7 | 0.008649 | 0.009238 | 3.992288 | 4.016609 |
| 676.45 | 0.008621 | 0.009205 | 3.99223 | 4.021399 |
| 678.16 | 0.008602 | 0.009181 | 3.992223 | 4.021382 |
| 679.91 | 0.00858 | 0.00916 | 3.992373 | 4.021399 |
| 681.62 | 0.008578 | 0.00915 | 3.992438 | 4.026279 |
| 683.37 | 0.008552 | 0.009136 | 3.992414 | 4.026315 |
| 685.08 | 0.008516 | 0.009105 | 3.992631 | 4.026873 |
| 686.84 | 0.008513 | 0.0091 | 3.992624 | 4.031176 |
| 688.59 | 0.008487 | 0.009071 | 3.992505 | 4.031178 |
| 690.3 | 0.008482 | 0.009045 | 3.992416 | 4.032154 |
| 692.05 | 0.008444 | 0.009024 | 3.992342 | 4.036066 |
| 693.76 | 0.008432 | 0.008997 | 3.992326 | 4.036056 |
| 695.51 | 0.008406 | 0.008974 | 3.992245 | 4.037592 |
| 697.23 | 0.008389 | 0.008957 | 3.992233 | 4.040887 |
| 698.98 | 0.008368 | 0.008935 | 3.992238 | 4.040884 |
| 700.68 | 0.008354 | 0.008909 | 3.992204 | 4.041371 |
| 702.43 | 0.008337 | 0.008885 | 3.992164 | 4.045767 |
| 704.14 | 0.008325 | 0.008883 | 3.992176 | 4.045767 |
| 705.89 | 0.008301 | 0.008873 | 3.992187 | 4.045774 |
| 707.6 | 0.008296 | 0.008838 | 3.992061 | 4.050676 |
| 709.35 | 0.008268 | 0.008838 | 3.992187 | 4.050676 |
| 711.07 | 0.008254 | 0.008809 | 3.992311 | 4.050679 |
| 712.82 | 0.008234 | 0.00878 | 3.992207 | 4.054746 |
| 714.52 | 0.008218 | 0.008759 | 3.992204 | 4.055552 |
| 716.28 | 0.008187 | 0.008733 | 3.992197 | 4.05555 |
| 718.03 | 0.008172 | 0.008716 | 3.992192 | 4.055719 |
| 719.75 | 0.008151 | 0.008692 | 3.992264 | 4.060506 |
| 721.5 | 0.008137 | 0.008678 | 3.992345 | 4.060506 |
| 723.2 | 0.008127 | 0.008654 | 3.992335 | 4.060504 |
| 724.95 | 0.008108 | 0.008645 | 3.992393 | 4.065005 |
| 726.66 | 0.008082 | 0.008628 | 3.992383 | 4.065406 |
| 728.41 | 0.008065 | 0.008599 | 3.99229 | 4.065403 |
| 730.12 | 0.008044 | 0.008575 | 3.992269 | 4.065401 |
| 731.87 | 0.008044 | 0.008549 | 3.992316 | 4.070303 |
| 733.58 | 0.008015 | 0.008552 | 3.992335 | 4.070303 |
| 735.33 | 0.007998 | 0.008509 | 3.992586 | 4.070293 |
| 737.04 | 0.007991 | 0.008499 | 3.99235 | 4.070334 |
| 738.79 | 0.007967 | 0.008471 | 3.992321 | 4.075174 |
| 740.5 | 0.007922 | 0.008454 | 3.992559 | 4.075183 |
| 742.26 | 0.007913 | 0.008413 | 3.992469 | 4.075186 |
| 744.01 | 0.007913 | 0.008423 | 3.992543 | 4.075183 |
| 745.73 | 0.007886 | 0.008394 | 3.992505 | 4.079856 |
| 747.48 | 0.007879 | 0.008375 | 3.992455 | 4.079995 |
| 749.18 | 0.007824 | 0.008351 | 3.99239 | 4.079999 |
| 750.93 | 0.007824 | 0.008342 | 3.992061 | 4.079999 |
| 752.64 | 0.007779 | 0.008301 | 3.992128 | 4.082145 |
| 754.39 | 0.007781 | 0.00828 | 3.99224 | 4.084887 |
| 756.1 | 0.00777 | 0.00827 | 3.992199 | 4.084894 |
| 757.85 | 0.00776 | 0.008246 | 3.992285 | 4.084904 |
| 759.57 | 0.007746 | 0.008227 | 3.99229 | 4.084908 |
| 761.32 | 0.007715 | 0.008208 | 3.992333 | 4.088308 |
| 763.02 | 0.0077 | 0.008177 | 3.992302 | 4.089784 |
| 764.77 | 0.007679 | 0.00817 | 3.992302 | 4.089813 |

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| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 766.48 | 0.007665 | 0.008141 | 3.992321 | 4.089808 |
| 768.23 | 0.007655 | 0.008127 | 3.992333 | 4.089822 |
| 769.94 | 0.007615 | 0.008094 | 3.992357 | 4.092698 |
| 771.7 | 0.0076 | 0.008091 | 3.99239 | 4.09465 |
| 773.45 | 0.007598 | 0.008063 | 3.992357 | 4.094679 |
| 775.16 | 0.007567 | 0.008029 | 3.992381 | 4.094665 |
| 776.91 | 0.007545 | 0.00802 | 3.992373 | 4.094662 |
| 778.62 | 0.007529 | 0.007989 | 3.992421 | 4.094994 |
| 780.37 | 0.00751 | 0.007948 | 3.992321 | 4.099457 |
| 782.08 | 0.007488 | 0.007946 | 3.992328 | 4.099457 |
| 783.83 | 0.007469 | 0.007927 | 3.992424 | 4.09945 |
| 785.54 | 0.007445 | 0.007894 | 3.992519 | 4.099447 |
| 787.29 | 0.007433 | 0.007882 | 3.992502 | 4.09945 |
| 789 | 0.00741 | 0.00786 | 3.992605 | 4.101653 |
| 790.75 | 0.00741 | 0.007822 | 3.992536 | 4.10433 |
| 792.46 | 0.007379 | 0.007822 | 3.992512 | 4.104335 |
| 794.21 | 0.007355 | 0.007796 | 3.992443 | 4.104335 |
| 795.92 | 0.007345 | 0.00776 | 3.992383 | 4.104344 |
| 797.67 | 0.007326 | 0.007753 | 3.992352 | 4.104335 |
| 799.39 | 0.007302 | 0.007727 | 3.992381 | 4.104321 |
| 801.14 | 0.007286 | 0.007703 | 3.992362 | 4.107413 |
| 802.89 | 0.007269 | 0.007681 | 3.992316 | 4.109256 |
| 804.6 | 0.007252 | 0.007672 | 3.992333 | 4.109261 |
| 806.35 | 0.00724 | 0.00765 | 3.992302 | 4.109241 |
| 808.07 | 0.007209 | 0.007634 | 3.992269 | 4.109256 |
| 809.82 | 0.007195 | 0.007598 | 3.992245 | 4.109251 |
| 811.52 | 0.007178 | 0.007574 | 3.992304 | 4.109411 |
| 813.27 | 0.007164 | 0.007562 | 3.992311 | 4.113149 |
| 814.98 | 0.00715 | 0.007541 | 3.992261 | 4.114122 |
| 816.73 | 0.007114 | 0.007517 | 3.992319 | 4.114103 |
| 818.44 | 0.007107 | 0.007493 | 3.99224 | 4.114127 |
| 820.19 | 0.007083 | 0.007476 | 3.9923 | 4.114129 |
| 821.91 | 0.007061 | 0.007452 | 3.992316 | 4.114136 |
| 823.66 | 0.007042 | 0.007429 | 3.99235 | 4.114129 |
| 825.36 | 0.007033 | 0.007393 | 3.992397 | 4.114906 |
| 827.11 | 0.007014 | 0.007388 | 3.992362 | 4.118874 |
| 828.82 | 0.006995 | 0.007355 | 3.992321 | 4.118928 |
| 830.58 | 0.006985 | 0.007336 | 3.992209 | 4.118945 |
| 832.33 | 0.006966 | 0.007319 | 3.992199 | 4.118945 |
| 834.04 | 0.006959 | 0.007295 | 3.992273 | 4.118928 |
| 835.79 | 0.006926 | 0.007281 | 3.99234 | 4.118926 |
| 837.5 | 0.006899 | 0.007269 | 3.992328 | 4.118938 |
| 839.25 | 0.006887 | 0.007255 | 3.9923 | 4.118943 |
| 840.96 | 0.006861 | 0.007212 | 3.992285 | 4.118926 |
| 842.71 | 0.006849 | 0.007109 | 3.992257 | 4.123818 |
| 844.42 | 0.006814 | 0.007078 | 3.992285 | 4.12383 |
| 846.17 | 0.006809 | 0.007061 | 3.99229 | 4.123826 |
| 847.89 | 0.00678 | 0.007028 | 3.992273 | 4.123814 |
| 849.64 | 0.006775 | 0.007014 | 3.99228 | 4.123811 |
| 851.34 | 0.006756 | 0.006978 | 3.992288 | 4.123821 |
| 853.09 | 0.006742 | 0.006942 | 3.99228 | 4.123826 |
| 854.8 | 0.006721 | 0.006933 | 3.992304 | 4.12383 |
| 856.55 | 0.00669 | 0.00693 | 3.992309 | 4.123811 |
| 858.26 | 0.006673 | 0.006909 | 3.992295 | 4.123821 |
| 860.02 | 0.006663 | 0.006873 | 3.992359 | 4.124588 |
| 861.77 | 0.006659 | 0.006859 | 3.992342 | 4.127497 |
| 863.48 | 0.006647 | 0.006833 | 3.992319 | 4.128723 |
| 865.23 | 0.006611 | 0.006816 | 3.992288 | 4.128727 |
| 866.94 | 0.006594 | 0.00679 | 3.992254 | 4.12873 |
| 868.69 | 0.00658 | 0.006771 | 3.99224 | 4.12873 |
| 870.41 | 0.006568 | 0.006766 | 3.992309 | 4.128735 |
| 872.16 | 0.006568 | 0.006728 | 3.992288 | 4.12873 |
| 873.86 | 0.00653 | 0.006701 | 3.9923 | 4.128727 |
| 875.61 | 0.006504 | 0.006692 | 3.992328 | 4.12872 |
| 877.32 | 0.006499 | 0.006666 | 3.992328 | 4.128723 |
| 879.07 | 0.006482 | 0.006639 | 3.992319 | 4.12872 |
| 880.78 | 0.006458 | 0.00662 | 3.992311 | 4.12873 |
| 882.53 | 0.006442 | 0.006608 | 3.9923 | 4.12873 |
| 884.25 | 0.006437 | 0.00658 | 3.992273 | 4.128735 |

| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 886 | 0.006401 | 0.006554 | 3.992285 | 4.130837 |
| 887.75 | 0.006387 | 0.006515 | 3.992216 | 4.131724 |
| 889.46 | 0.00637 | 0.006499 | 3.992261 | 4.133617 |
| 891.21 | 0.006358 | 0.006496 | 3.992257 | 4.13361 |
| 892.92 | 0.006346 | 0.006468 | 3.992309 | 4.133605 |
| 894.67 | 0.006339 | 0.006446 | 3.992366 | 4.133613 |
| 896.39 | 0.006313 | 0.006418 | 3.992383 | 4.133613 |
| 898.14 | 0.006282 | 0.006399 | 3.992381 | 4.133601 |
| 899.84 | 0.006253 | 0.006384 | 3.992278 | 4.133617 |
| 901.59 | 0.006256 | 0.006356 | 3.992278 | 4.133603 |
| 903.3 | 0.006229 | 0.006334 | 3.9923 | 4.133601 |
| 905.05 | 0.006217 | 0.00631 | 3.992335 | 4.133589 |
| 906.76 | 0.006191 | 0.006289 | 3.992321 | 4.133603 |
| 908.51 | 0.006165 | 0.00626 | 3.992273 | 4.133613 |
| 910.23 | 0.006153 | 0.006241 | 3.992319 | 4.133591 |
| 911.98 | 0.006146 | 0.00621 | 3.992309 | 4.133601 |
| 913.68 | 0.006124 | 0.006203 | 3.992321 | 4.13361 |
| 915.44 | 0.006108 | 0.006177 | 3.992304 | 4.133586 |
| 917.19 | 0.006101 | 0.006153 | 3.992285 | 4.133603 |
| 918.91 | 0.00607 | 0.006124 | 3.992273 | 4.133596 |
| 920.66 | 0.006051 | 0.006115 | 3.992302 | 4.133596 |
| 922.36 | 0.006041 | 0.006105 | 3.992345 | 4.133586 |
| 924.11 | 0.006017 | 0.006067 | 3.992328 | 4.133601 |
| 925.82 | 0.006008 | 0.006058 | 3.992397 | 4.133601 |
| 927.57 | 0.006 | 0.006027 | 3.992433 | 4.133589 |
| 929.28 | 0.005981 | 0.005991 | 3.992414 | 4.133884 |
| 931.03 | 0.005979 | 0.005991 | 3.992385 | 4.135241 |
| 932.75 | 0.005941 | 0.005974 | 3.992407 | 4.134902 |
| 934.5 | 0.005939 | 0.005943 | 3.992383 | 4.135036 |
| 936.2 | 0.00591 | 0.005919 | 3.992319 | 4.135038 |
| 937.95 | 0.005898 | 0.0059 | 3.992335 | 4.135916 |
| 939.66 | 0.005865 | 0.005869 | 3.992309 | 4.136195 |
| 941.41 | 0.005853 | 0.005843 | 3.992233 | 4.137644 |
| 943.12 | 0.005826 | 0.005822 | 3.992245 | 4.136271 |
| 944.89 | 0.005817 | 0.005812 | 3.992321 | 4.13814 |
| 946.64 | 0.005815 | 0.005784 | 3.992359 | 4.137816 |
| 948.34 | 0.005791 | 0.005779 | 3.992352 | 4.137816 |
| 950.09 | 0.005767 | 0.00576 | 3.992383 | 4.137327 |
| 951.8 | 0.005748 | 0.005722 | 3.992295 | 4.137337 |
| 953.55 | 0.005724 | 0.0057 | 3.992278 | 4.13794 |
| 955.26 | 0.005736 | 0.005676 | 3.99224 | 4.137392 |
| 957.01 | 0.005693 | 0.005664 | 3.99229 | 4.13696 |
| 958.73 | 0.005667 | 0.005633 | 3.99228 | 4.137394 |
| 960.48 | 0.005664 | 0.005609 | 3.992381 | 4.137167 |
| 962.18 | 0.00564 | 0.005598 | 3.992288 | 4.137353 |
| 963.93 | 0.005629 | 0.005574 | 3.992247 | 4.135601 |
| 965.64 | 0.005629 | 0.00555 | 3.992326 | 4.135863 |
| 967.39 | 0.005595 | 0.005533 | 3.992543 | 4.133753 |
| 969.1 | 0.005581 | 0.005521 | 3.99265 | 4.133794 |
| 970.85 | 0.005564 | 0.005488 | 3.992552 | 4.133601 |
| 972.57 | 0.005559 | 0.005469 | 3.992402 | 4.133591 |
| 974.32 | 0.005521 | 0.005464 | 3.992366 | 4.133582 |
| 976.07 | 0.005526 | 0.005433 | 3.992309 | 4.133596 |
| 977.78 | 0.005502 | 0.005426 | 3.992309 | 4.133586 |
| 979.53 | 0.005481 | 0.005395 | 3.992257 | 4.133586 |
| 981.25 | 0.005452 | 0.005369 | 3.992288 | 4.133579 |
| 983 | 0.005431 | 0.005338 | 3.992264 | 4.133589 |
| 984.7 | 0.005426 | 0.005319 | 3.99228 | 4.133589 |
| 986.45 | 0.005421 | 0.005311 | 3.992247 | 4.133601 |
| 988.16 | 0.005414 | 0.005285 | 3.992335 | 4.133589 |
| 989.91 | 0.005388 | 0.005273 | 3.992373 | 4.133591 |
| 991.62 | 0.005369 | 0.005245 | 3.992278 | 4.133572 |
| 993.37 | 0.005345 | 0.005223 | 3.992233 | 4.133574 |
| 995.08 | 0.005345 | 0.005202 | 3.992125 | 4.133586 |
| 996.83 | 0.005323 | 0.005183 | 3.992209 | 4.133591 |
| 998.54 | 0.005319 | 0.005173 | 3.9923 | 4.133589 |
| 1000.29 | 0.00529 | 0.00514 | 3.992385 | 4.133582 |
| 1002 | 0.005266 | 0.005137 | 3.992285 | 4.133582 |
| 1003.76 | 0.005242 | 0.005099 | 3.992288 | 4.133572 |

| Time mark | Ext 1 (output volts) | Ext 2 (output volts) | Input volts | Load |
|---|---|---|---|---|
| 1005.51 | 0.005242 | 0.00508 | 3.992085 | 4.133586 |
| 1007.23 | 0.005214 | 0.005059 | 3.992209 | 4.133126 |
| 1008.98 | 0.005197 | 0.005044 | 3.9923 | 4.129796 |
| 1010.68 | 0.005187 | 0.005011 | 3.992385 | 4.128696 |
| 1012.43 | 0.00518 | 0.005006 | 3.992345 | 4.128696 |
| 1014.14 | 0.005173 | 0.004994 | 3.992335 | 4.128704 |
| 1015.89 | 0.005149 | 0.004961 | 3.992342 | 4.128723 |
| 1017.6 | 0.005145 | 0.004963 | 3.992311 | 4.128713 |
| 1019.35 | 0.005118 | 0.004916 | 3.992316 | 4.128713 |
| 1021.07 | 0.005106 | 0.004911 | 3.992488 | 4.128718 |
| 1022.82 | 0.005097 | 0.004904 | 3.992478 | 4.128723 |
| 1024.52 | 0.005078 | 0.004875 | 3.992352 | 4.12872 |
| 1026.27 | 0.005071 | 0.004866 | 3.992309 | 4.128077 |
| 1027.98 | 0.005047 | 0.004856 | 3.992328 | 4.123828 |
| 1029.75 | 0.005044 | 0.00483 | 3.99229 | 4.123828 |
| 1031.5 | 0.005028 | 0.004823 | 3.992316 | 4.123818 |
| 1033.2 | 0.005002 | 0.004801 | 3.992328 | 4.12383 |
| 1034.95 | 0.005002 | 0.004768 | 3.992309 | 4.123806 |
| 1036.66 | 0.004982 | 0.004754 | 3.992369 | 4.123818 |
| 1038.41 | 0.004982 | 0.004739 | 3.992362 | 4.123108 |
| 1040.12 | 0.004959 | 0.004732 | 3.992316 | 4.118921 |
| 1041.87 | 0.004959 | 0.004742 | 3.992383 | 4.118936 |
| 1043.58 | 0.004942 | 0.004715 | 3.992352 | 4.118936 |
| 1045.33 | 0.004925 | 0.004711 | 3.992335 | 4.118921 |
| 1047.04 | 0.004916 | 0.004682 | 3.992316 | 4.116573 |
| 1048.79 | 0.004894 | 0.004682 | 3.992311 | 4.114129 |
| 1050.5 | 0.004901 | 0.004668 | 3.992321 | 4.114108 |
| 1052.25 | 0.004882 | 0.004665 | 3.992326 | 4.113945 |
| 1053.96 | 0.004866 | 0.004651 | 3.992335 | 4.109239 |
| 1055.71 | 0.004875 | 0.004634 | 3.992342 | 4.109232 |
| 1057.42 | 0.004866 | 0.004639 | 3.99239 | 4.10434 |
| 1059.18 | 0.004849 | 0.004625 | 3.992393 | 4.104337 |
| 1060.93 | 0.004837 | 0.004613 | 3.992376 | 4.09944 |
| 1062.64 | 0.004842 | 0.004613 | 3.992373 | 4.09944 |
| 1064.39 | 0.004813 | 0.004599 | 3.992409 | 4.09466 |
| 1066.1 | 0.00482 | 0.004589 | 3.992373 | 4.090716 |
| 1067.85 | 0.004818 | 0.004599 | 3.992373 | 4.089765 |
| 1069.57 | 0.004813 | 0.004584 | 3.992424 | 4.08487 |
| 1071.32 | 0.004808 | 0.004575 | 3.992438 | 4.079983 |
| 1073.02 | 0.004808 | 0.004565 | 3.992376 | 4.075162 |
| 1074.77 | 0.004796 | 0.004575 | 3.99239 | 4.070267 |
| 1076.48 | 0.004799 | 0.004575 | 3.9924 | 4.061625 |
| 1078.23 | 0.004806 | 0.004572 | 3.992433 | 4.055557 |
| 1079.94 | 0.004792 | 0.004563 | 3.99244 | 4.049382 |
| 1081.69 | 0.004796 | 0.004568 | 3.992397 | 4.040884 |
| 1083.41 | 0.004801 | 0.004582 | 3.992385 | 4.031178 |
| 1085.16 | 0.004808 | 0.004582 | 3.992414 | 4.02373 |
| 1086.86 | 0.004796 | 0.004575 | 3.99239 | 4.01628 |
| 1088.62 | 0.004804 | 0.004582 | 3.992333 | 4.004576 |
| 1090.37 | 0.004799 | 0.004575 | 3.992316 | 3.99244 |
| 1092.08 | 0.004796 | 0.004553 | 3.992316 | 3.982417 |
| 1093.83 | 0.004799 | 0.004589 | 3.992261 | 3.972337 |
| 1095.54 | 0.004796 | 0.004584 | 3.992333 | 3.958072 |
| 1097.29 | 0.004808 | 0.004575 | 3.9923 | 3.946468 |
| 1099 | 0.004806 | 0.004558 | 3.99229 | 3.933722 |
| 1100.75 | 0.004794 | 0.004568 | 3.99223 | 3.919115 |
| 1102.46 | 0.004804 | 0.004553 | 3.992257 | 3.904428 |
| 1104.21 | 0.004808 | 0.004572 | 3.992321 | 3.888697 |
| 1105.92 | 0.004801 | 0.004568 | 3.992321 | 3.871698 |
| 1107.67 | 0.004806 | 0.004582 | 3.99239 | 3.855378 |
| 1109.39 | 0.00482 | 0.004575 | 3.992352 | 3.791966 |
| 1135.36 | 0.004823 | 0.004599 | 3.992328 | 3.724131 |

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1. REPORT IDENTIFYING INFORMATION

A. ORIGINATING AGENCY

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943

B. REPORT TITLE AND/OR NUMBER

SHIP HULL PLATING AND WELD MISALIGNMENT EFFECTS
WHEN SUBJECTED TO TENSION

C. MONITOR REPORT NUMBER

BY: M. CAMERON WEAVER, MIT

D. PREPARED UNDER CONTRACT NUMBER

N62271-97-G-0026

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